KULICKE and SOFFA
INDUSTRIES, INC.

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AUTOMATED SOLAR MODULE

ASSEMBLY LINE

FINAL REPORT

AUCUST 1980

MAX BYCER

JPL CONTRACT NO. 955287

KULICKE and SOFFA INDUSTRIES, INC.
5C7 Prudential Road
Horsham, PA 19044

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE".

ABSTRACT

The solar module assembly machine which Kulicke and Soffa delivered under this contract is a cell tabbing and stringing machine, flexible in design, and capable of handling a variety of cells and assembling strings up to 4 feet long which then can be placed into a module array up to 2 feet by 4 feet in a series or parallel arrangement, and in a straight or interdigitated array format. The machine cycle is 5 seconds per solar cell. This machine is primarily adapted to 3 inch diameter round cells with two tabs between cells. Pulsed heat is used as the bond technique for solar cell interconnects.

The solar module assembly machine unloads solar cells from a cassette, automatically orients them, applies flux and solders interconnect ribbons onto the cells. It then inverts the tabbed cells, connects them into cell strings, and delivers them into a module array format using a track mounted vacuum lance, from which they are taken to test and cleaning benches prior to final encapsulation into finished solar modules. Throughout the machine the solar cell is handled very carefully, and any contact with the collector side of the cell is avoided or minimized.

A lamp simulator has been used to test bonded solar cells to determine if the bonding operation had any degrading effect on the cell. I-V profile curves taken of these sample cells, before and after the bonding operation indicate no apparent effect on the electrical characteristics of the solar cell by the bonding operation.

PREFACE

This is the final technical report on Contract No. 955287 between the Jet Propulsion Laboratory, California Institute of Technology (JPL) and Kulicke and Soffa Industries, Inc. (K&S). The JPL Technical Program Manager for the contract was Lloyd Sanchez.

This report covers the activity and work performed under this contract under the supervision of Albert Soffa as Program Director, with Max Bycer as Program Manager, and Walter Frasch as Project Design Leader.

The cooperation of RCA Laboratories and Robert D'Aiello is hereby acknowledged for making their solar cell electrical test system available to K&S for use on this project. This electrical test system was a great help in the testing program for the machine delivered under this contract.

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SECTION 1

1. INTRODUCTION

This contract is part of the Near Term Implementation of Flat Plate Photovoltaic Cost Reduction Program under the Low-Cost Solar Array Project. It is directed toward accelerating the reduction in cost of any activity related to the production of flat plate photovoltaic modules during the period 1979 to 1981.

In this contract, Kulicke and Soffa Industries, Inc. (K&S) designed, built, and delivered to the Jet Propulsion Laboratory, California Institute of Technology (JPL) an automated assembly line (See Figure 1) for a typical solar module and solar cell to be approved by JPL in accordance with the following goals:

(a) Flexible automated solar module assembly line which shall be adaptable to as many manufacturers' processes as possible.

(b) The equipment shall permit the assembly of up to a six-string module.

(c) Adaptable to permit strings to be assembled in series or series parallel relationship.

(d) Machine cycle of 5 seconds per cell.

(e) An automated solar module assembly line yield of 95% or better.

KULICKE and SOFFA

INDUSTRIES, INC.

AUTOMATED SOLAR MODULE ASSEMBLY LINE

JPL CONTRACT NO. 955287

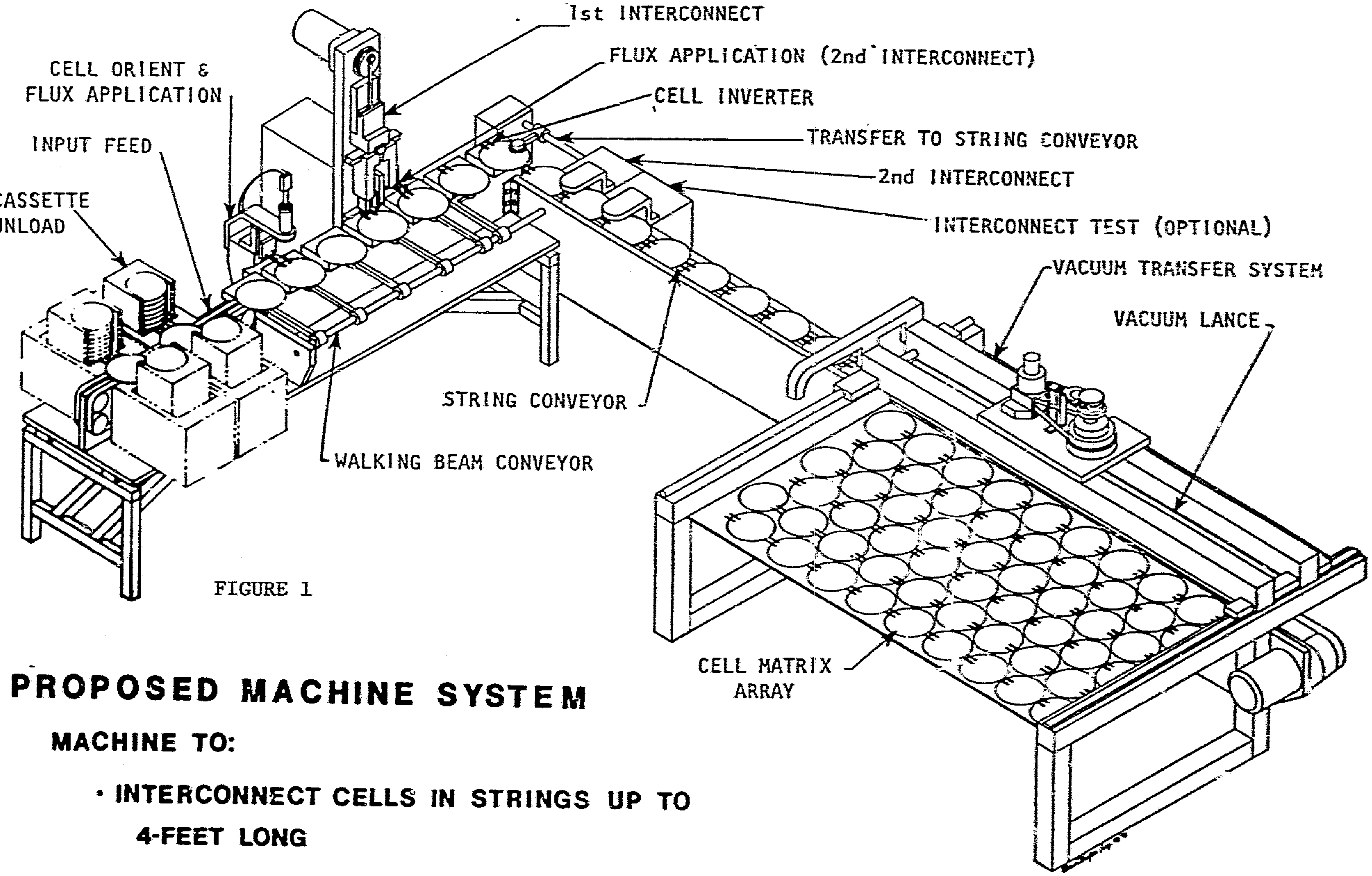


FIGURE 1

PROPOSED MACHINE SYSTEM

MACHINE TO:

- **INTERCONNECT CELLS IN STRINGS UP TO 4-FEET LONG**
- **HANDLE 3-INCH DIAMETER SOLAR CELLS [ADAPTABLE TO 100 mm DIAMETER CELLS]**

TARGET MACHINE CYCLE: 5 SECONDS/CELL

SECTION 2

2. TECHNICAL DISCUSSION

2.1 Project Stages

In the execution of the project, the work was accomplished in the following stages:

(a) Information gathering stage - the gathering of information that led to the design approach of the machine.

(b) Preliminary design stage - conceptual design work that led to the machine system proposed at the project design review.

(c) Design and development stage - the actual design and development of each station of the machine, including the building of mock-ups or prototypes, where beneficial, to verify some design aspects before final design and building.

(d) Assembly and debug of machine - this included the building and check-out of some individual stations where indicated, prior to being installed on the machine.

(e) Performance testing of machine - running cells through the whole machine in its various modes to verify performance of machine.

The details of each of these stages in the project are presented below.

2.2 Information Gathering

In order to gather information as to the state-of-the-art of the solar module manufacturing industry, leading up to the machine considerations and design approach for the machine, K&S used the following methods:

(a) Literature Review

(b) Field trips to solar module manufacturers

(c) Consultations

2.2.1 Literature Review

In order to get an effective bibliography as quickly and efficiently as possible, K&S utilized the computer assisted information retrieval service, DIALOG, of the University of Pennsylvania. This search yielded articles from the following sources:

(a) National Technical Information Service (NTIS)

(b) COMPENDEX

(c) INSPEC

In addition, JPL forwarded pertinent technical reports from LSSA program as requested by K&S. Together, the above material formed an effective starting bibliography of reference material for the project.

2.2.2 Field Trips to Solar Module Manufacturers

Several field trips were made to solar module manufacturers to get their comments as to what an automated solar module assembly should consist of. The companies visited on these field trips are:

(a) Sensor Technology (Photowatt, International)
(b) Spectrolab
(c) OCLI (Applied Solar Energy)
(d) Arco Solar
(e) Solarex
(f) Solar Power
(g) Mobil Tyco

The salient points affecting machine design that were brought out on these visits are discussed in Section 2.3.

2.2.3 Consultations

K&S utilized Professor Martin Wolf, University of Pennsylvania, and Dr. Thomas Matcovich, Drexel University for this project for consultations with them in the areas of photovoltaic and micro-electronic technologies, since they both are recognized experts in these fields. There have been frequent consultations with them in these areas.

When it became apparent that the interconnect technique for near term implementation would be soldering (See Section 2.3.6), a consultation was arranged with Howard Manko, an acknowledged expert in this field. The use of solder and solder techniques in the manufacture of solar modules, and applying the best technology available that would be compatible to an automated assembly line of equipment, were discussed at great length. Mr. Manko had reservations about the reliability of a no-flux system for an application where reliability and long life are important and strongly recommended a solder system with flux for our application.

Further investigations into soldering techniques led to consultations with Lepel, Inc. on induction heating since this technique lent itself to simultaneous soldering of multiple leads (or ribbons) onto multiple pads.

2.3 Areas of Study That Affect Machine Design

The areas of study in the information gathering stage are discussed in the following paragraphs. In each paragraph are summarized the findings for the given topic as it affected machine considerations and design approach for the module assembly line designed and built under this contract.

2.3.1 Cell Sizes and Shapes

Most common cell sizes utilized for the near term were circular cells of 3 inch and 100 mm diameter and 0.010 to 0.020 inches thick. Other modules had square, hexagonal, semi-circular cells or quarter circular cells.

2.3.2 Module Sizes

The modules that were discussed had various outside dimensions with widths up to 18 inches, and lengths up to 48 inches. The number of strings varied up to five. The space requirements alloted for module array handling was 2 feet by 4 feet modules, with up to 6 strings/module.

2.3.3 Top Surface Treatment

Top sufaces were treated to maximize collector efficiency either by a texturize etch and/or a spray-on anti-reflective coating. Because of the ease in which microscopic pinnacles are fractured from the texturized surface, it was suggested that the equipment be designed to minimize any cell handling requirements touching the top surface of the cell.

2.3.4 String Configurations

Some modules had their cells interconnected in a continuous series of strings while others had several series of strings joined in parallel via the interconnect on the back plane or bus bar of the module. In some of the

observed strings the end cells were oriented differently than the other cells in the string in order to be in position to make a series interconnect to a cell in the next string. Some modules were arranged so that all the cells in a given row of the module were not part of the same string.

The machine was designed to handle modules with all the cells in a given row as part of the same string with the cells in each string oriented the same way so as to be more compatible with an automated assembly line.

2.3.5 Interconnect Configurations

The cells observed had various interconnect configurations. The ribbons observed were both solid material and mesh ribbons. The cells had various number and length of interconnects from one short tab (ribbon interconnect) to two interconnect ribbons running the full length across a 100 mm cell. These interconnects had various bond patterns from a single bond to a series of up to 25 bond pads per ribbon on each of two ribbons (for a total of 50 bonds on a side). The cantilever overhang of the ribbons ran from a short distance (approximately 1/4 inch) to over 3 inches long.

Optimum interconnect configuration for machine considerations would be to have a minumum cantilever length beyond the cell and be of sufficient stiffness and cross-section to facilitate handling in assembly equipment.

2.3.6 Interconnect Bonding Technique

The solar module manufacturers who were visited used some kind of solder technique for making their interconnects on both top and bottom surfaces as well as making the interconnects of the cell string to the back plane or bus bar of the module assembly. These manufacturers indicated that it would be desirable for the equipment to incorporate a soldering technique that would meet their requirements.

Some of the soldering options were:

(a) Pulse/Parallel Gap
(b) Steady State/Soldering Iron
(c) Infrared Heating
(d) Induction Heating
(e) Laser
(f) Vapor Phase Reflow

Several bonding methods were considered. Because induction heating lent itself well to the diversity of interconnect configurations to be handled by the machine, the ability to bond multiple pads simultaneously, and the cleanliness of tooling and speed of soldering, it was the bond method initially proposed, with pulsed heating as the back-up candidate technique. Further development led to the decision to use pulsed heating as the bond technique. This is discussed in greater detail in Section 2.4.

2.3.7 Fluxing Operation

Each of the solar module manufacturers included a fluxing operation as part of the soldering technique in making the interconnects. They indicated that they would prefer to maintain this step as part of the process. This operation has been incorporated in the machine design for attaching both the 1st and 2nd (string) interconnects.

2.3.8 Cleaning Operation

Each of the solar module manufacturers incorporated a cleaning or defluxing operation after the tab interconnects were made. While a cleaning station is not part of the machine to be built, the design approach for the machine is to accomplish this function after the module array interconnects have been made and clean the entire array at one time.

2.3.9 Testing of Tabbed Cells and Strings

The solar module manufacturers incorporated an electrical test of the cell strings or arrays at some point in their process prior to the encapsulation operation. Many module manufacturers incorporated an electrical test of the complete array, just prior to encapsulation, after all operations are performed on it. There was divided opinion as to the specified need or desire to incorporate this function within an assembly machine. With proper monitoring of bond parameters, periodic off-line sampling would achieve the same results. The machine, as originally proposed, was to contain a station to test each cell pair after the string interconnect was made. However, due to time and financial restraints, this station was omitted from the machine that was built, and would be offered only as an option in future replications.

2.4 Bonding Experiments

After careful consideration of the various options for the bonding technique (See Section 2.3.6), the decision was made to pursue induction heating as the prime candidate for the bonding technique, with pulsed heating as the back-up bond technique.

Induction heat bonding was chosen as the prime bond technique because it appeared to lend itself well to the wide range of interconnect configurations that was encountered on the trips to the various solar module manufacturers, as well as having the ability to bond multiple pads simultaneously. Since the induction heating does not require the bonding energy to be applied through a tool that would engage the interconnect ribbon, tool cleanliness should not be a problem with this bond technique. Also, the speed of the bonding action seemed consistent with the desired time requirements (machine cycle of 5 seconds/cell).

Pulsed heating was chosen as a back-up bond technique because it involved less risk. It is a widely used and understood bond technique, which permits fast, controllable, and uniform soldering action. Tool cleanliness is a matter to be concerned with in pulsed heat technology.

Early in the development stage of the project, preliminary interconnect bonding experiments were conducted on a prototype bond station (See Figure 2) utilizing both induction heat and pulsed heat techniques. Several different cells were used in these tests in order to meet the requirement of having the equipment be adaptable to many manufacturer's processes as possible. These early tests included 3 inch and 100mm diameter cells, and involved solder dipped and silver plated cells, liquid and paste flux, solder paste, pretinned mesh and ribbon.

2.4.1 Induction Heat Bonding Experiments

The induction heat bonding tests gave some indication of a wide heat distribution pattern that may produce a minimum of thermal shock to the cell.

Large quantities of heat can be applied quite rapidly to the area of the cell to be bonded without having the bonding tool touch the work. This makes tool cleanliness less of a problem.

For the pulsed heat bonding tests we utilized a Lepel 2-1/2 KW 450 KHz induction heat generator unit. We fitted this with an eight turn coil of 1/8 diameter copper tubing water cooled, with a cross section of rectangular configuration of 1-3/8" X 3/4". This coil, which acts as the primary of an air core transformer and is able to reciprocate in a Z direction, was placed in the concentrator. (See Figure 3).

The function of the concentrator is to receive the energy from the primary and by its design direct it to the area to be bonded. The theoretical design of the concentrator is quite complicated and is optimized empirically. The concentrator design must be adapted to the cell pattern and interconnect configuration in order for the heat to be applied in the most efficient manner without causing any negative aspects.

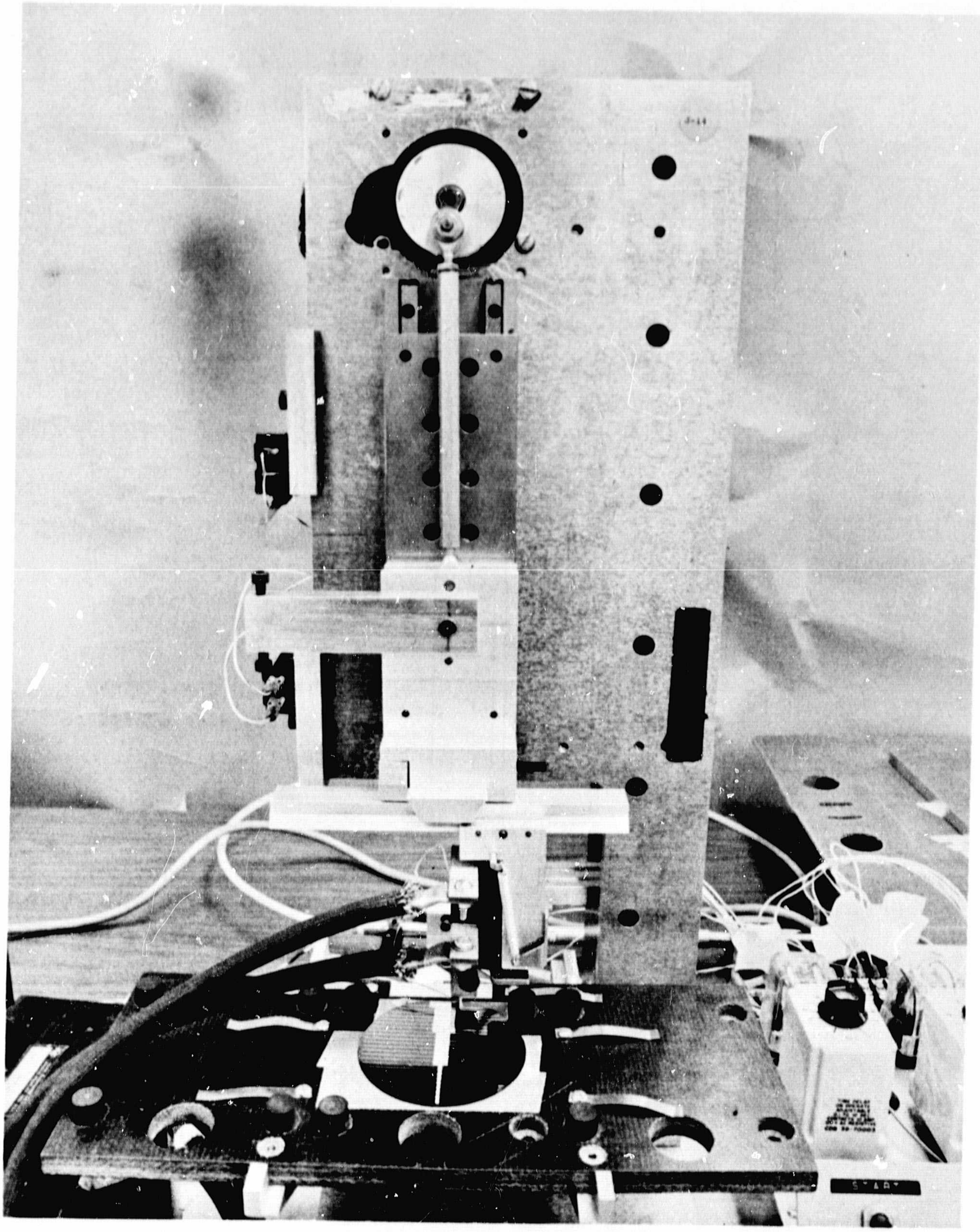
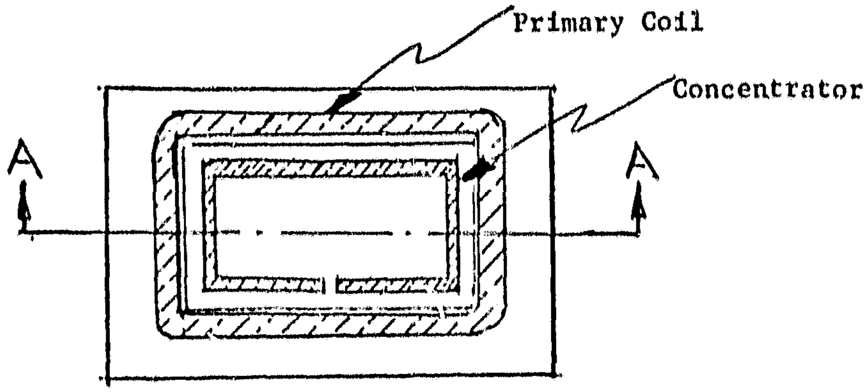
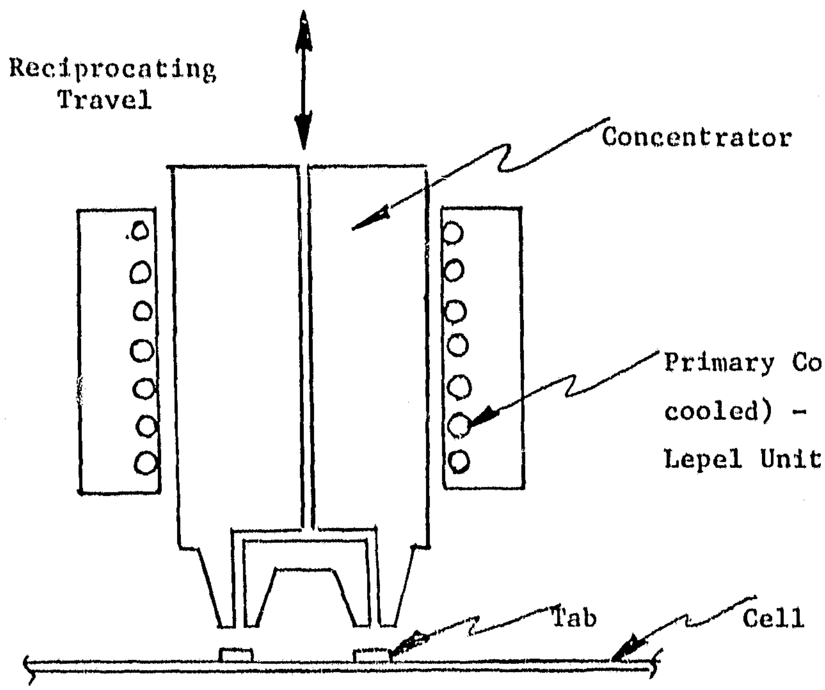


FIGURE 2 - PROTOTYPE BOND STATION





SECTION AA

Figure 3 -- PRIMARY COIL AND CONCENTRATOR OF INDUCTION HEAT TOOLING

The prototype bond station raised and lowered the concentrator over the cell and ribbons to be bonded. To this station was added a control system which would bring the concentrator bonding head into position, turn on the 450 KHz energy for a preset time, dwell until the bond has cooled and then retract to permit removal of the cell.

We experimented with a variety of solder dipped cells and used flux in our soldering proces. In bonding tinned copper ribbons to some solder dipped cells we found great differences in the adhesion of the metallization to the cell. Consequently, in many instances where the solder joints appeared quite good, they peeled off very easily since they were limited to the strength of adhesion of the metallization to the cell. We found variations in pull strength of from less than 50 grams to more than 1000 grams, using 60-40 tinned copper soft ribbon (.004" thick X .1875" wide).

Another difficulty encountered was the variation in thickness of the solder on the cell. On some cells the solder layer varied from 1 mil to 15 mils in places. In the best cells where an attempt to hold the solder thickness uniform by squeezing the molten solder on the cell, the solder thickness varied from 3 mils to 6 mils.

While this lack of uniformity may not be of consequence in hand soldering, it is of considerable importance in automatic bonding. In our experiments we dumped a fixed amount of heat into the bond (a setting of 600 mils plate current on the Lepel for 1 second). By increasing the plate current or the time setting more energy could be put into the bond. When the settings were made sufficient to bond in the thickest areas of the soldert on the cell, it resulted in too much melting and possible cell destruction in the areas where the solder was thin. In trying to localize the application of induction heat energy, as in the case of the sample solar cells which had interconnects cantilevered over edge of the cell, the solder on the backs of the cells seemed to be driven out from area where the induction heat energy. was applied. (See Figure 4).

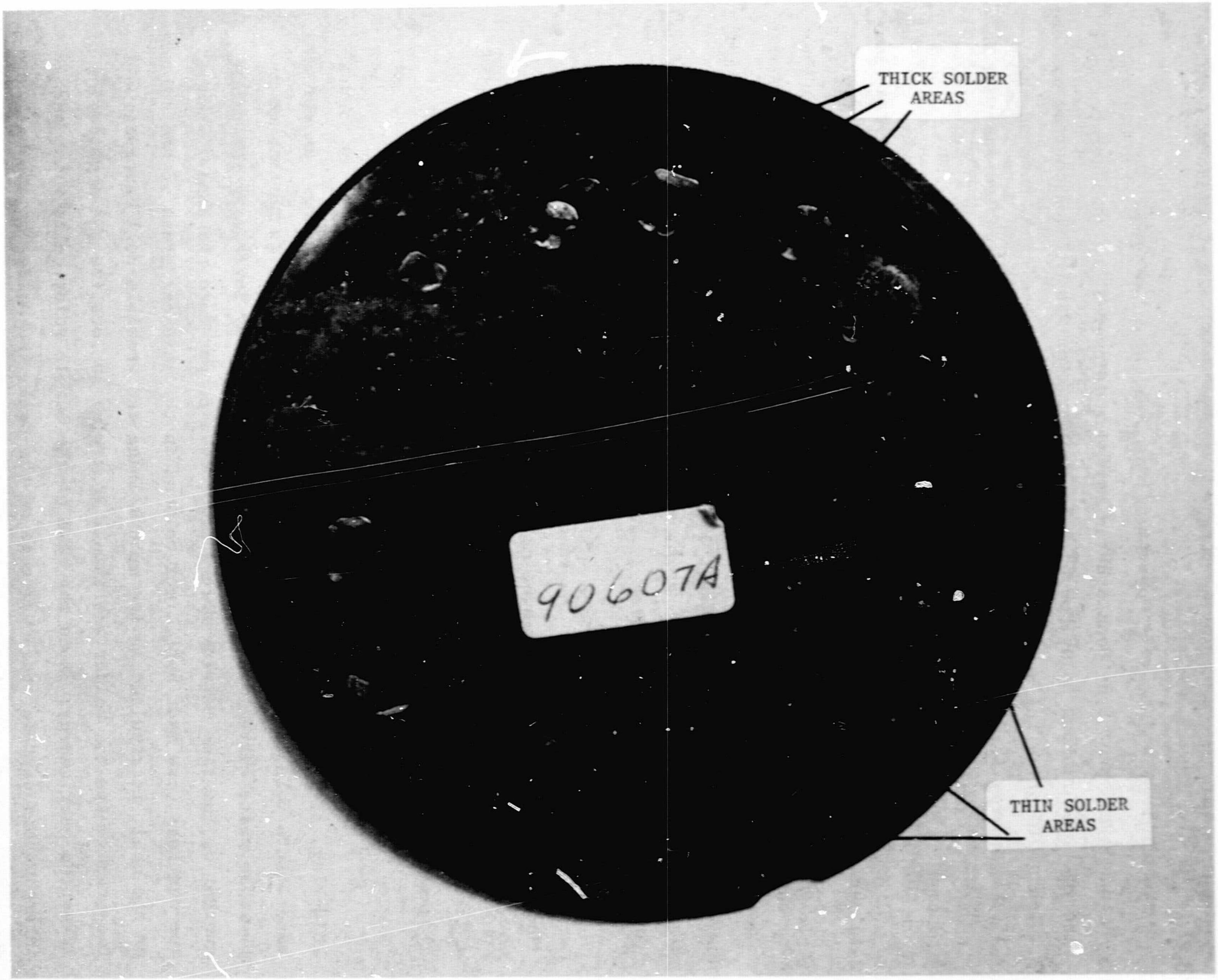


FIGURE 4 - SAMPLE INDUCTION HEAT MELTING IMPRINTS ON SOLDER-BACKED CELL

To overcome the variation in solder thickness and inject the proper amount of heat for each bond, it was decided to develop a control system to measure the bond temperature and cut off the bonding power when the proper temperature had been reached. Two methods were tried. First, a thermocouple was placed in the vicinity of the bond as the power was applied and an attempt was made to control the energy input with the thermocouple reading. Getting good mechanical contact with the thermocouple without damaging the cell was difficult. This method was abandoned in favor of a method depending on the breakdown of the cell junction as the temperature increases.

A current of about 1 ampere was passed through the cell. As the temperature of the cell increased the voltage drop across the cell decreased. A correlation was established between the voltage drop and the cell temperature. (See Table 1 and Figure 5). Electronic circuitry was developed to compare the cell voltage to a standard and actuate a relay when the proper point had been reached to turn off the energy going to the bond. Induction of voltage into the cell when the RF power was on interfered with this system.

The electronic measuring system was then modified to sample the temperature only during that portion of the cycle when the RF was off. Measuring the cell voltage drop in this system does not insure that the exact amount of heat goes into the junction but it is a closer approximation than controlling by time. Unfortunately insufficient cells had been bonded to determine the reliability of the bonds.

There were other areas that had to be investigated with induction bonding. The current induced into the cell solder coat is a closed loop. As the bond moves closer to the edge of the cell, the current sheet is squeezed so that its density becomes greater in a narrower area near the edge causing more IR heat generation near the edge. The result is that the amount of melt changes as you move in from the edge.

SOLAR POWER

TABLE 1 - CALIBRATION CHART

Thermocouple Reading ($^{\circ}F$)	Voltage Drop Across Cell (mV)	
65°	.550	
80°	.500	
100°	.450	
120°	.400	
140°	.350	
180°	.300	
200°	.250	← Scale Shift
220°	.225	
240°	.200	← Melt
280°	.160	
300°	.150	
280°	.175	
270°	.200	
260°	.200	

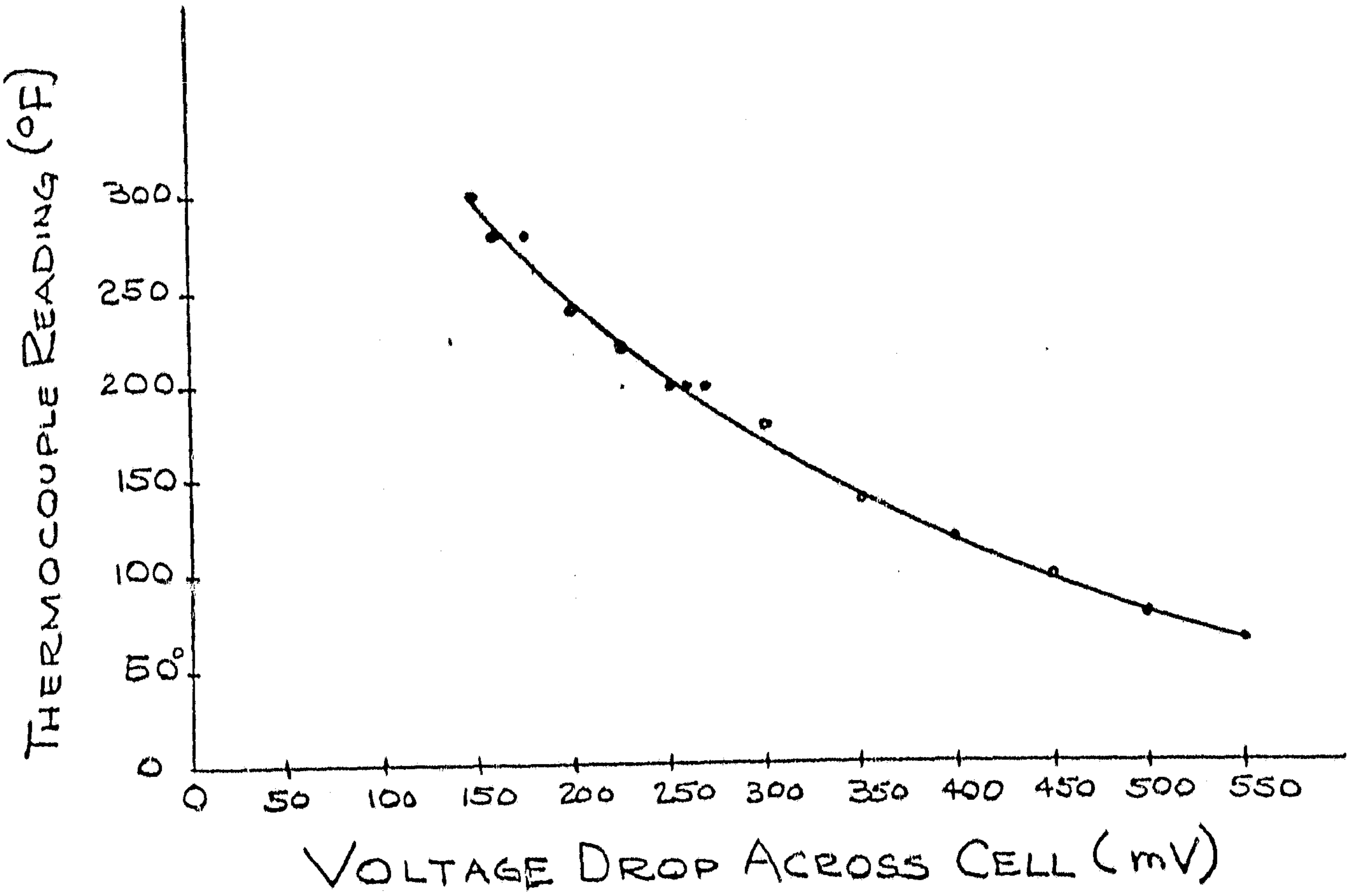

THERMOCOUPLE READING (°F)
300
250
200
150
100
50°
0
0
50
100
150
200
250
300
350
400
450
500
550
VOLTAGE DROP ACROSS CELL (mV)

FIGURE 5

Another area of concern was the fact that much less heat is generated in the copper ribbon than in the solder since the resistance of copper is about 1/10th that of solder. Consequently, the IR heat generation of the copper is smaller. Also, more refinement of the concentrator design was required to optimize its function.

Since more investigation and development remained to be accomplished on induction bonding of solar cells, the constraints of the contract schedule led to the decision to proceed with pulsed heat as the prime candidate for the bond technique.

2.4.2 Pulsed Heat Bonding Experiments

Interconnect tests were performed on the same cells using pulsed heat as the bond technique. A pulse bonding head replaced the induction bonding head on the same reciprocating and timing mechanism that was utilized for the induction bonding head. A modified K&S pulse bonding power supply was used in our K&S manual pulse bonders for the semiconductor industry, was utilized to control the pulsed heat bonding action. The pulse bonding head was spring loaded so that the force would be relatively consistent regardless of the minute differences in cell thickness or overtravel of the bond heads. A thermocouple controlled 3/16 inch square faced Hastelloy C tool was utilized in the head.

Relatively consistent bonds were achieved on a solder-backed 100 mm diameter cell with good metallization using an impulse time of 1-1/2 seconds and a dwell time of 3-1/2 seconds. Other cells tested were a 3" cell with solder backing and a 3" cell with evaporated silver metallization. A rosin flux was used on the solder-backed cells and a solder paste used on the silver-backed cells. Good results were obtained on the solder backed cells. The bonds were tested with a Scherr-Tumico 550 gram gauge pulling tabs vertically 90 from the cell face. All the bonds were tested and withstood 250 gram pull force. Good results were obtained on cells with solder backing and evaporated silver metallization was acceptable. (See Figure 6). Typically, bonds with low pull force readings failed at the metallization interface with the cell, i.e. the interconnects pulled the metallization off the cell without itself failing.

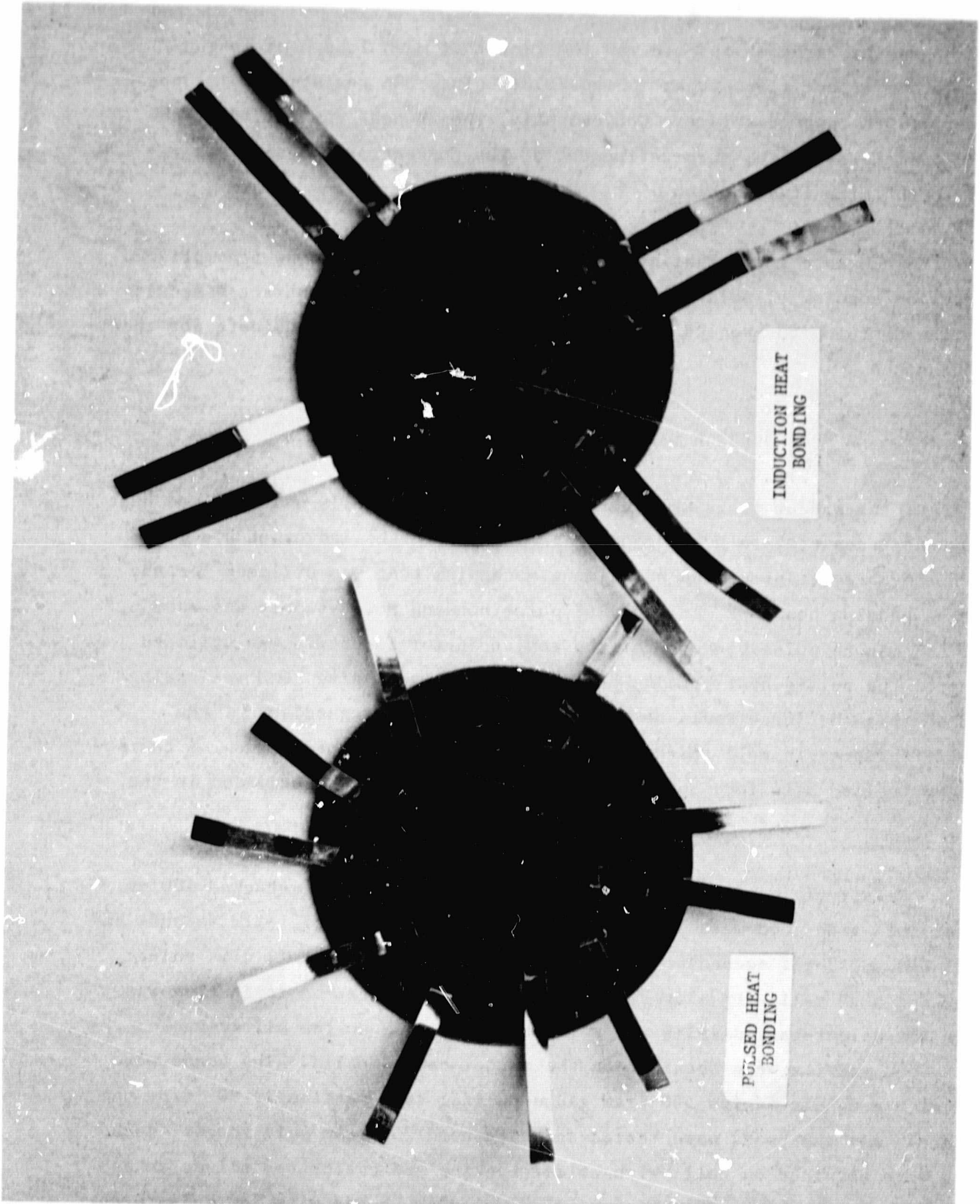


FIGURE 6 - SOLDER BACKED CELL (3 INCH DIAMETER) BONDED BY INDUCTION HEAT AND PULSED HEAT TECHNIQUE

The consistent bonds that were achieved quickly with the solder-backed cells, that varied in thickness, as well as the silver metallized cells, confirmed the decision to proceed with pulsed heat as the bond technique for the machine.

2.5 Description of Machine

The machine delivered under this contract is a cell tabbing and stringing machine, flexible in design, capable of handling a variety of cells and assembling strings of cells which can then be placed in a module array area up to 4' X 2' in series or parallel arrangement, and in a straight or interdigitated format. The machine cycle is 5 seconds per cell.

The solar cell for operation and testing purposes was a 3 inch diameter, manufactured by Applied Solar Energy Corporation. This cell was chosen because it was readily available, and was judged to be good representative of a cell compatible with automated means of assembly. Also, the cell's metallization (evaporated Ti-Pd-Ag) allowed the cells to run through the machine many times, which was a very helpful factor during the course of the project.

The machine was built to handle the assembly of this solar cell with two tabs between cells (See Figure 7). A typical module to be processed in the machine is shown in Figure 8. The design of the machine is flexible so that it can be modified to handle a variety of cell sizes, string lengths and module arrangements.

Solar cells are automatically dispensed from a 25 cell cassette and are conveyed by belts to a receiving station. (See Figures 9 and 10). From this point, each cell is picked up by a walking beam conveyor and placed in an orientation station. In this station the cell is rotated and automatically positioned optically so that the pattern is in position for tabbing. Flux is then applied to the tab assembly areas. This orientation is maintained in the subsequent stations until the cell has been assembled in the string. In the next station the tabs are formed and cut off from continuous reels of ribbon, transferred into position above the cells, and solder bonded by pulsed heating. In the next station flux is applied on the tab extensions.

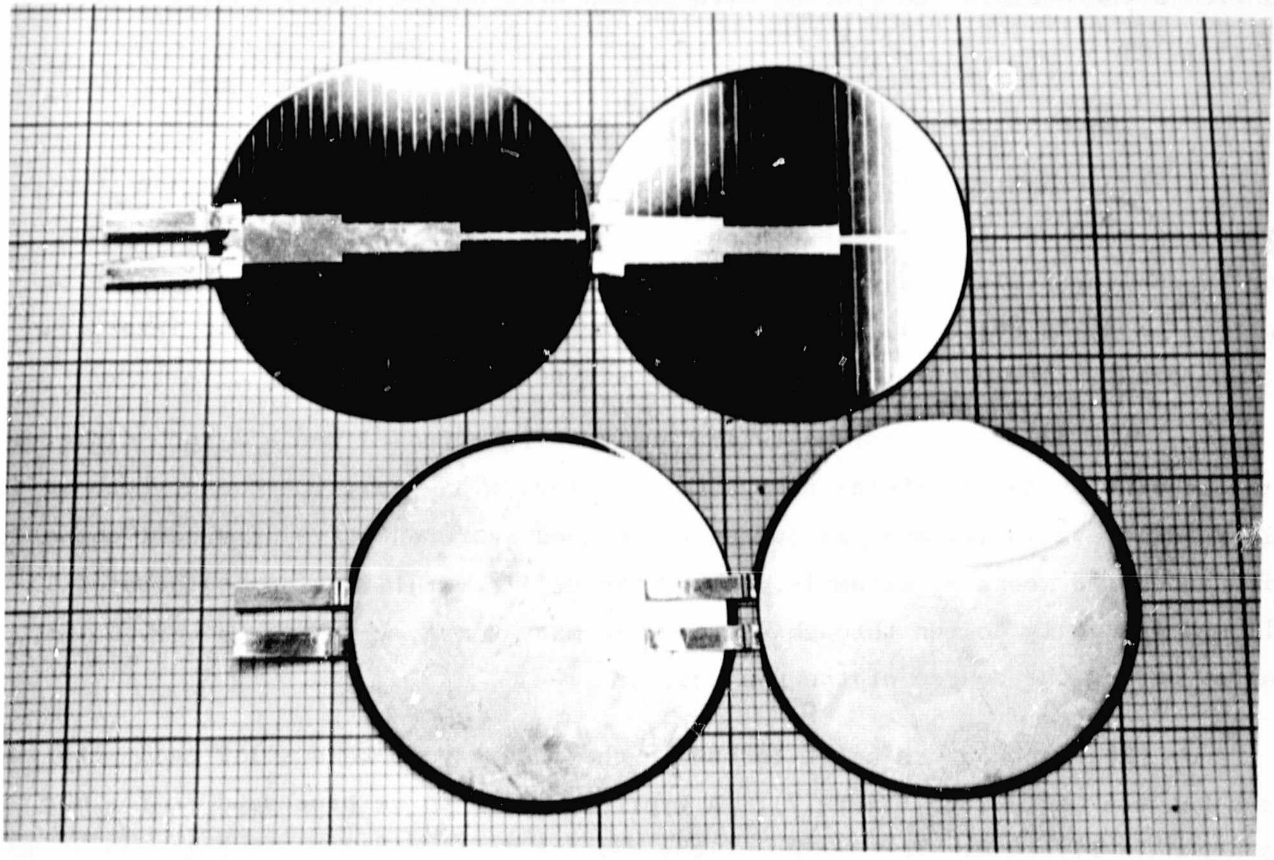


FIGURE 7 - SAMPLE SOLAR CELL - 3 INCH DIAMETER WITH TWO INTERCONNECTS

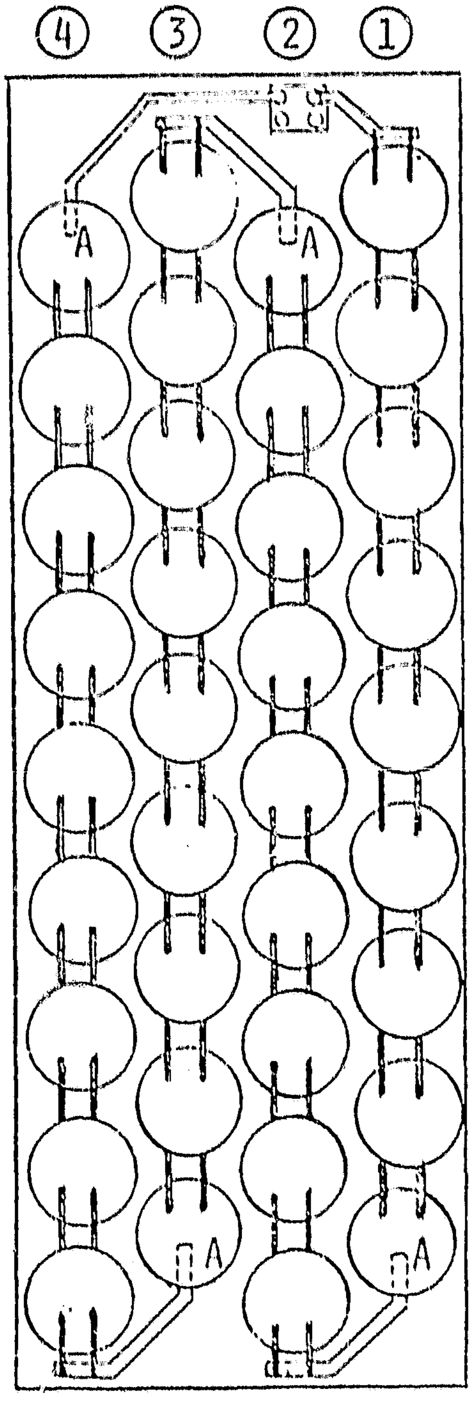


FIGURE 8 - TYPICAL MODULE

THIS MODULE HAS 4 IDENTICAL STRINGS IN SERIES AND REQUIRES MANUAL INTERCONNECTION OF THESE STRINGS AT 'A' (4 PLACES) AFTER THEY HAVE BEEN PLACED IN THE MATRIX.

FIGURE 9 - **SOLAR MODULE ASSEMBLY MACHINE**

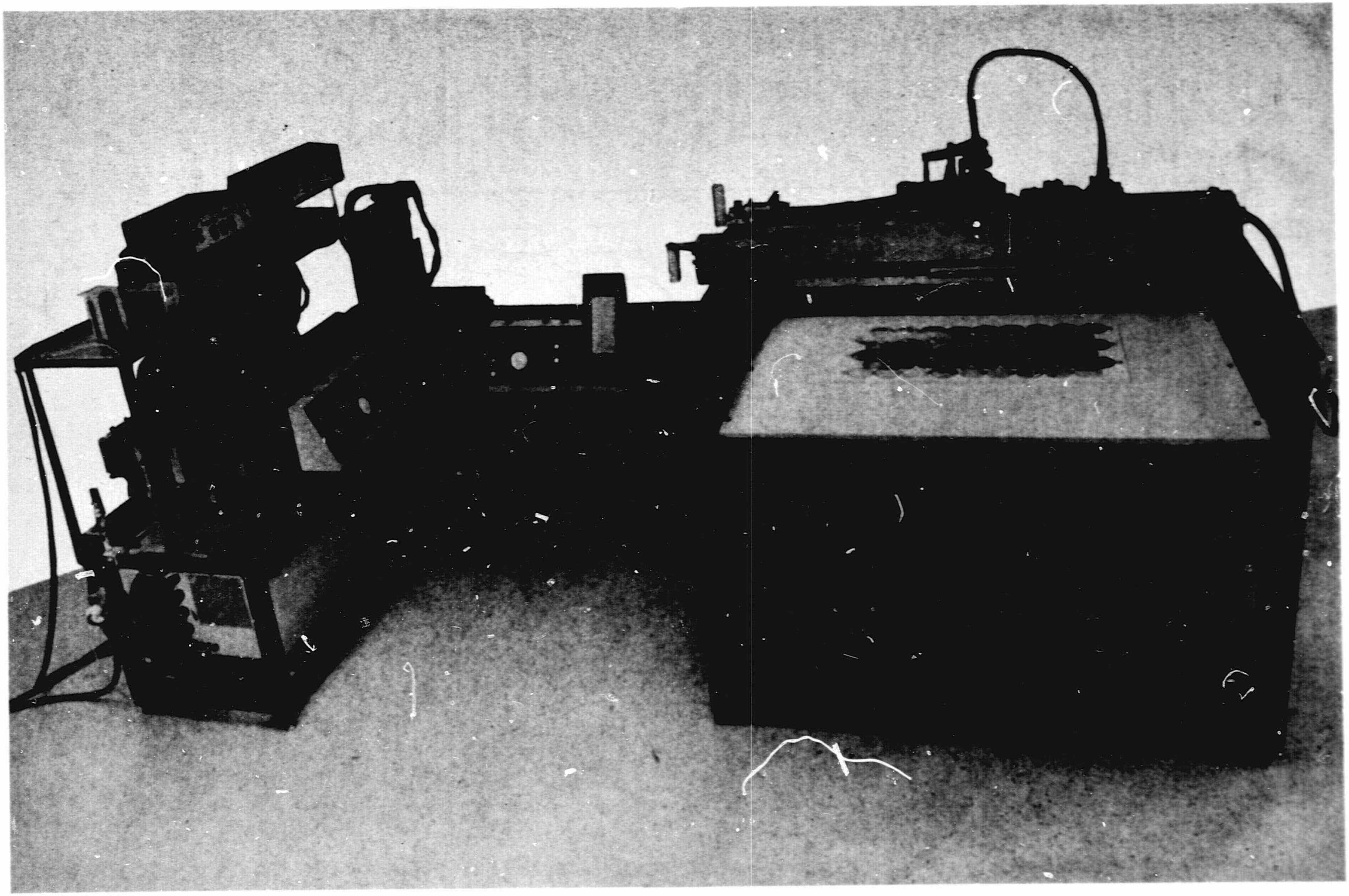
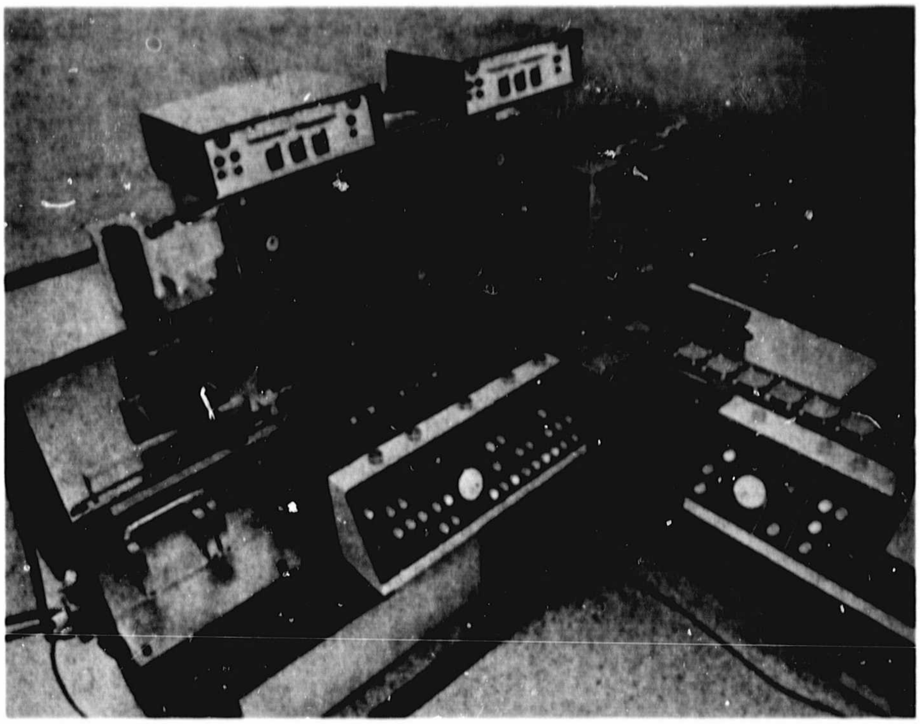
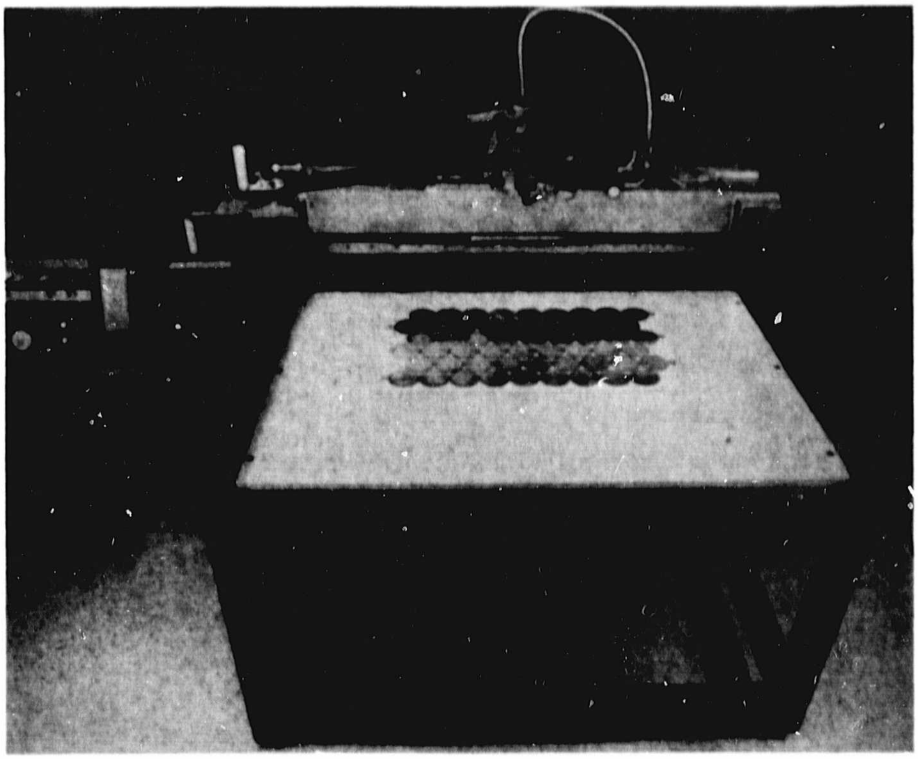


FIGURE 10

SOLAR MODULE ASSEMBLY MACHINE



CELL TABBING AND STRINGING AREA



STRING DELIVERY TO MODULE ARRAY AREA

The cell is then inverted and transferred to the string conveyor without loss of orientation. On this conveyor the cells are held in re - gistration to each other. The string interconnection is made in the first station on the string conveyor and can be tested in a subsequent station. When the string is completed, it is automatically picked up using a track-mounted vacuum lance and then placed into the module array area in a straight or interdigitated format to achieve the desired series or parallel arrangement. The module array can then have subsequent operations such as inter-stringing external lead connections, cleaning, etc. performed on it. The vacuum lance maintains the intercell mechanical spacing and a track is provided with detents to locate the strings for correct interstring spacing. A reject station is provided in the discharge area in case it is determined that the cell string should not be delivered to the module array area. A more detailed description of the various stations of the machine follows.

2.6 Machine Stations

2.6.1 Design Criteria

The design of the stations of the machine were designed with the following criteria in mind:

a. Handle the solar cells gently to avoid breakage.

b. Minimize contact on the collector side of the cell.

c. Achieve uniform and accurate fluxing operation.

d. Achieve accurate placement and uniform reliable bonding results in interconnect operation.

e. Minimize any thermal shock to the cell during bonding operation.

f. Maintain accuracy of solar cell positioning and registration, with regards to the station it is in and with adjacent cells in stringing operation.

g. Positive pick-up of string (including partial strings) and accurate placement of strings in straight or interdigitated module array format.

h. Easy accommodation of any module array format of strings within 2′ X 4′ range.

i. Easy changeover to other cell and interconnect sizes, shapes and configurations, and string lengths.

j. Easy access to control operations and servicing requirements.

2.6.2 Cassette Unload (Figure 11)

This station contains a Siltec Model 2601A cassette load/unload module. The 2601A module is designed to unload, with adjustment, cells from 2.0 to 5.0 inches in diameter from any standard 25-level "H"-bar bottom cassette with 3/16th inch pitch (Fluoroware PA-72 series or equivalent). The 2601A module comes equipped as a complete stand-alone unit with its own power supply control and load/unload platform. The machine as delivered will be equipped with two Fluoroware 3 inch cassettes. Both the Siltec load/unload module and the Fluoroware cassettes are widely used in the semiconductor and solar cell industry for wafer and cell handling operations. The use of these standard items will make them compatible to other equipment for this program. During the progress of the project, it became necessary to modify the controls of the Siltec unit to make it interface properly with the machine's microprocessor controls.

While the machine will be supplied with a single unloader module, it is designed to accommodate up to four (4) Siltec unload modules. When all of the unload stations are utilized, the microprocessor controls will read which unloaders are full and activate them in turn to dispense cells into the machine. This will allow the empty stations to be reloaded, while the other stations are feeding cells; thus maintaining a continuous supply of cells to the machine.

2.6.3 Output Feed From Cassette (Figure 11)

In this station the solar cells, which are automatically dispensed from the unload module in Station One, are conveyed by urethane belts to a receiving station from which they are indexed through the machine. The receiving station is adjustable to receive 3 inch or 100 mm diameter solar cells.

2.6.4 Walking Beam Conveyor (Figure 11)

The walking beam conveyor is the indexing system that moves the cells through the various stations until it is transferred onto the string conveyor. Essentially, the walking beam conveyor is a mechanism which picks up each cell individually, advances it to the next station where the cell is deposited for the function of that station, after which the mechanism re-

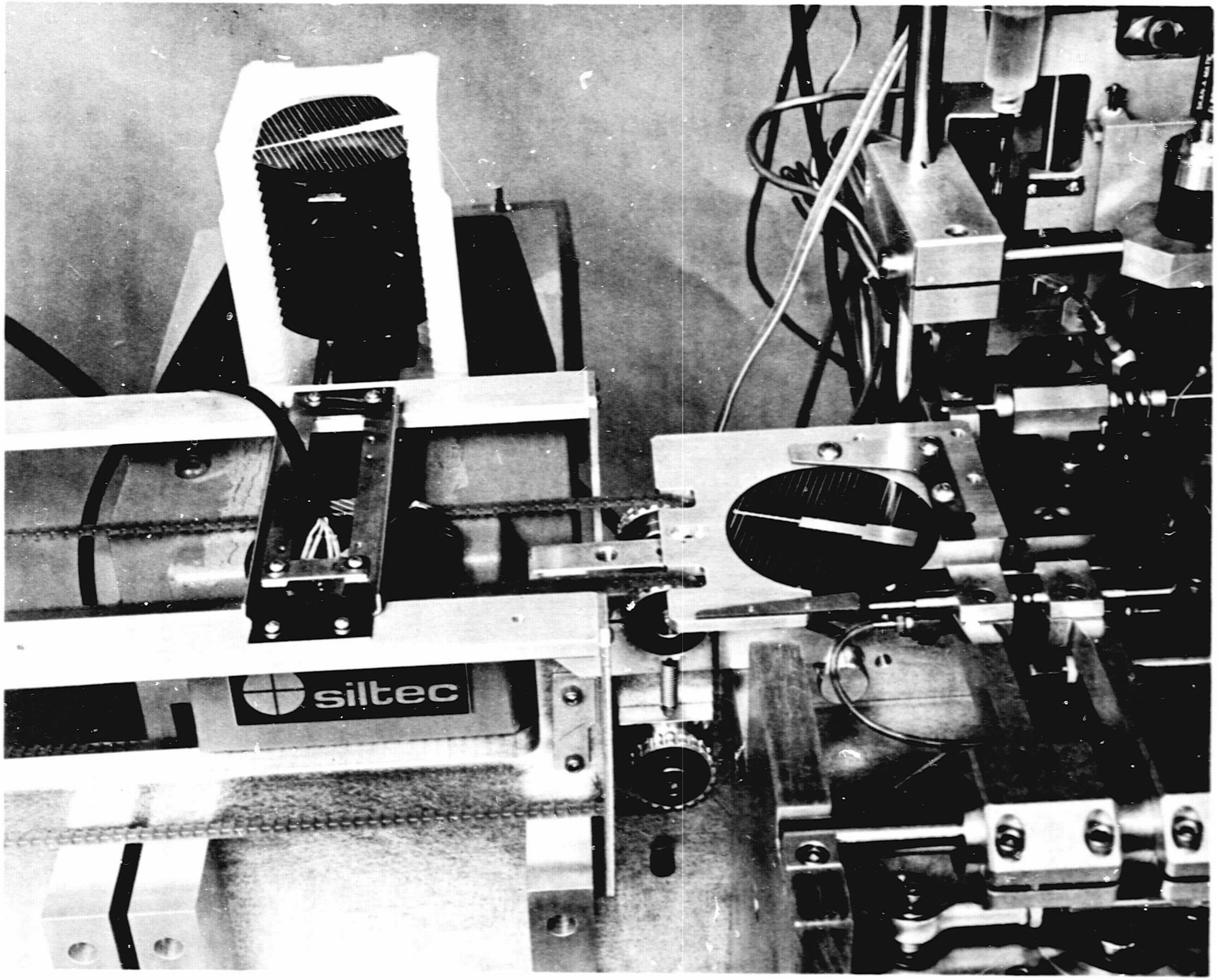


FIGURE 11 - CASSETTE UNLOAD AND INPUT TO MACHINE - SHOWING BELT AND WALKING BEAM CONVEYOR SYSTEMS

tracks back to be in position for the next index. This indexing system contains a drive system which is controlled by the microprocessor for the machine and a common shaft which houses all of the indexing arms for the system. The pick-arm mechanism is a vacuum work-face with a soft silicone rubber vacuum cup for a strong, but gentle, grip on the cell, so that the cell does not lose its orientation during the indexing action.

The work platform of the functional stations that receives the solar cells from the walking beam have vacuum-hold-down systems. The walking beam system transfers the cell to the workstage of the functional station via a "handshake" technique, - i.e. the vacuum of the workstage is turned on to hold the cell in position before the vacuum system of the walking beam conveyor system is turned off. In this way, the proper registration of the solar cell is maintained.

2.6.5 Cell Orient and Flux Application (Figures 12 and 13)

The solar cell is placed onto a platform in the station where it is rotated and automatically positioned optically so that the pattern is in position for tabbing. Once the correct orientation is achieved for the cell, this orientation is maintained in the subsequent stations until the cell has been assembled into a string on the string conveyor.

The proper cell orientation is accomplished by a driving wheel in the center of the workstage, which urges the cell towards the back against two capstans. These capstan wheels engage the cell on the periphery and rotate the cell, which is being observed under an optic scanning system. The scanning system detects the pattern of the cell, signals the controls system, which stops the drive system when the cell reaches its proper orientation. The drive system is set to accomplish maximum rotation of 360 in 2 seconds or less. The capstan wheels are adjustable to the rear to accommodate 100 mm diameter cells with no further disassembly.

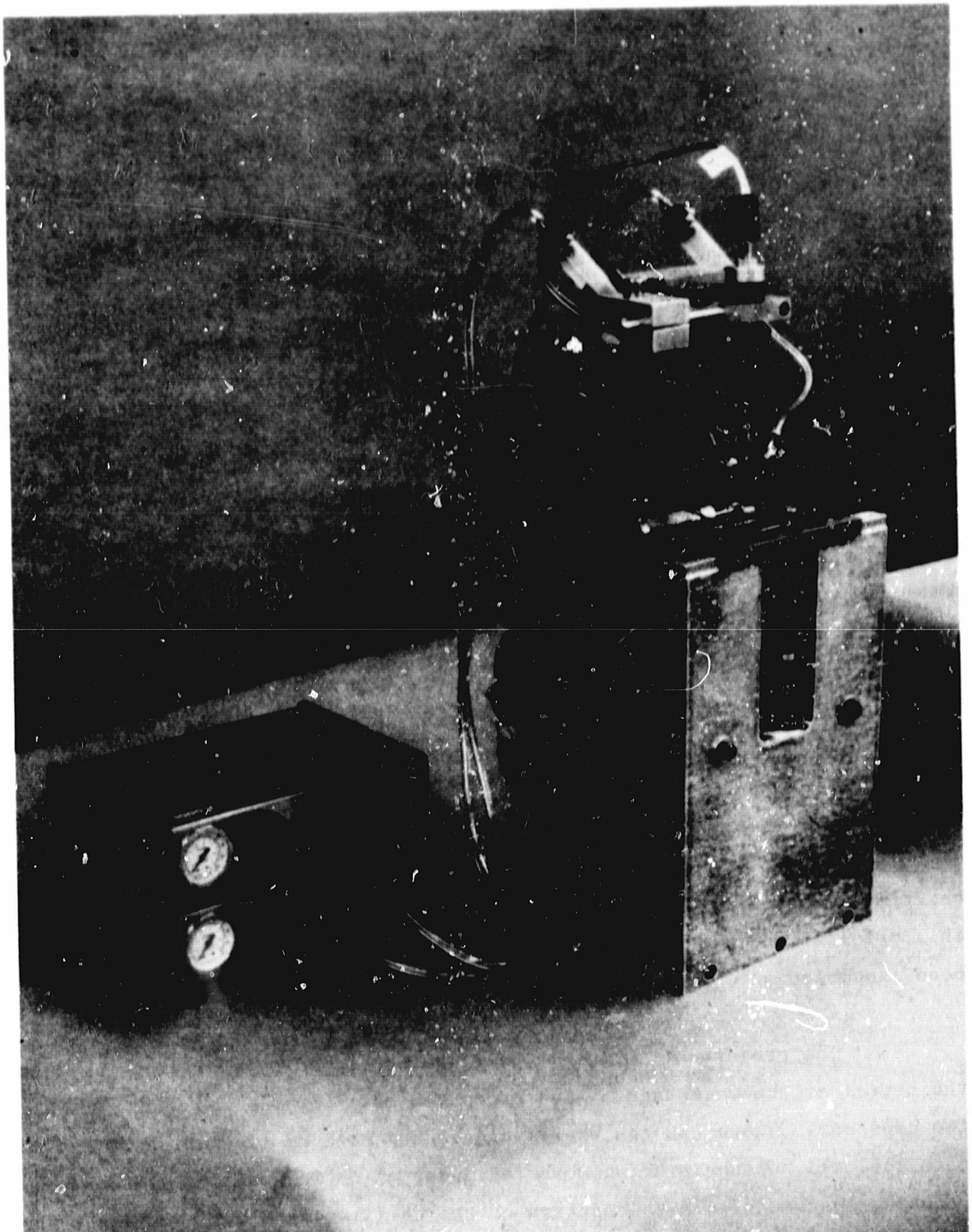


FIGURE 12 - THETA ORIENT STATION WITH FLUX APPLICATION SYSTEM

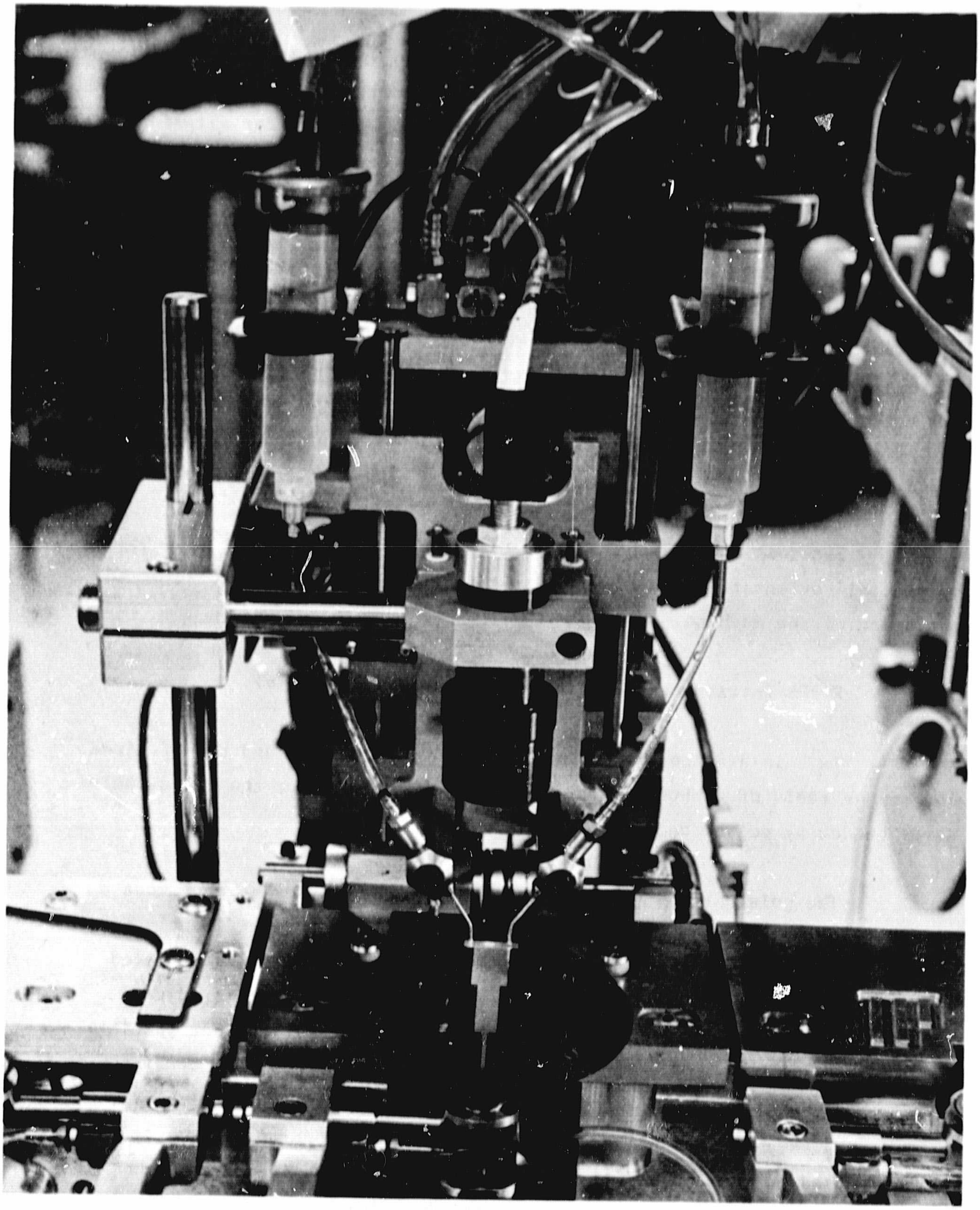


FIGURE 13 - CELL ORIENT AND FLUX APPLICATION STATION

The above describes the cell orientation system used to deal with the round cells supplied on the project. If the cell had flats, or uses square or rectangular, the straight edges would be utilized for alignment purposes, thus minimizing or eliminating the need for the optical scanning system.

With cell in proper registration, flux is then applied to the cell in the area where the interconnects are to be bonded. (See Figure 13). An EFD Model 1000V-1000 dispenser system was used in the machine at each flux application station. Each dispenser system controlled both flux dispensing tubes at each station. The flux used was Superior #77 water soluble flux which was modified to have slightly heavier viscosity for better dispensing and drip control.

Sections 2.8.4.3 and 2.8.4.4 discusses the experiences encountered by the cell orientation and flux application systems during the testing and operation of the machine.

2.6.6 First Interconnect Station (Figures 14, 15 and 16)

In this station the interconnect tabs are formed and cut-off from continuous reels of ribbon, transferred into position above the cells, soldered bonded by pulsed heating. (See Figure 16)

The pulsed bonding head is spring loaded in order to accommodate minor variations in cell thickness and planarity without significantly affecting the bond force. A thermocouple controlled 3/16 inch square faced Hastellay C tool was utilized in the head. Each bonding tool is adjustable in X and Y direction to accommodate a variety of interconnect spacings as well as different size cells, individually controlled for the bonding parameters (temperature, time, force, etc.). The bonding tools are water-cooled to ensure uniform bond quality. A K&S pulsed bonding power supply, which is used on the K&S manual pulse bonders for the semiconductor industry, was used to control the bonding operation. The power supply was modified to accommodate the power and heat requirements of this application.

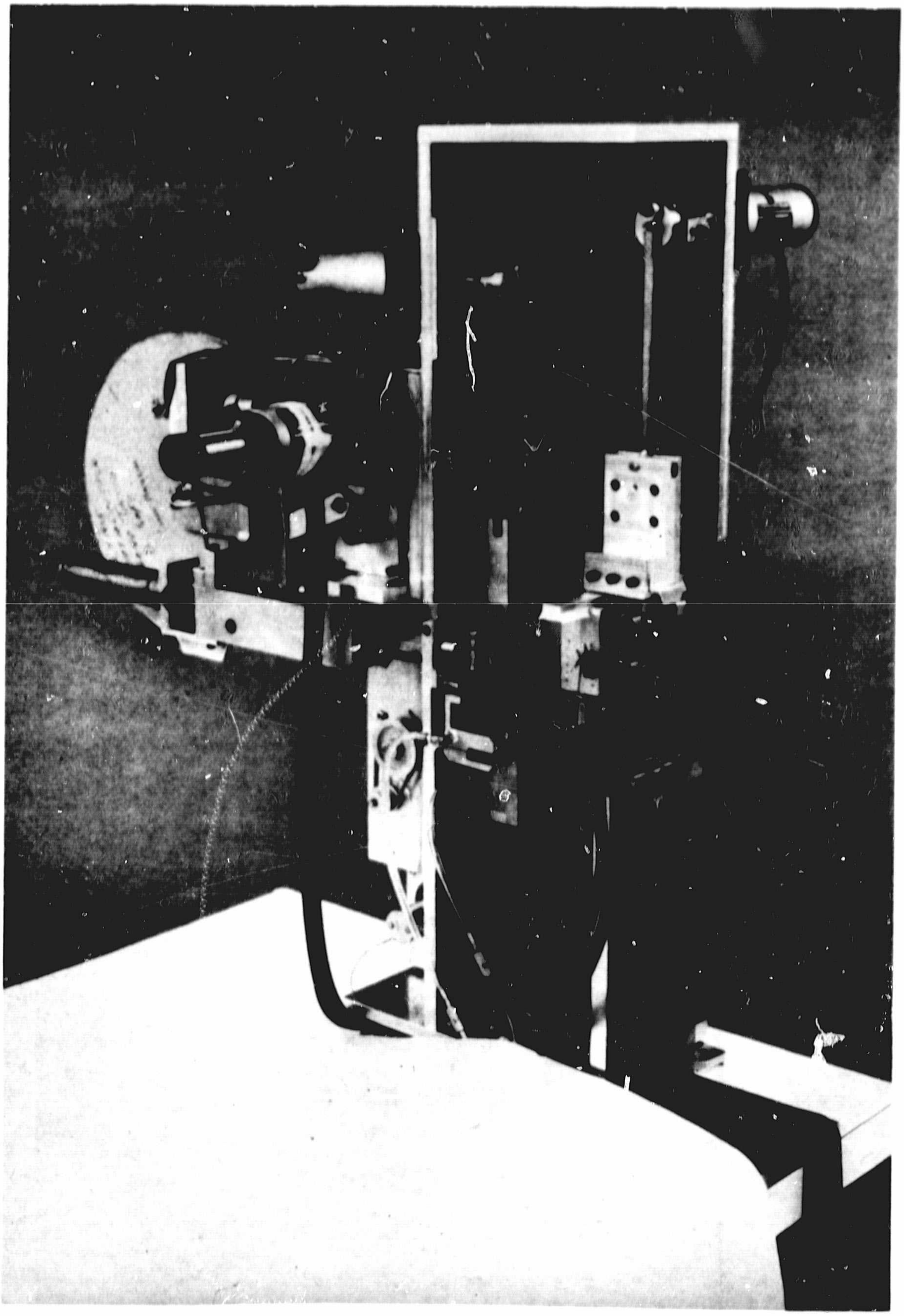


FIGURE 14 - FIRST INTERCONNECT (BOND) STATION

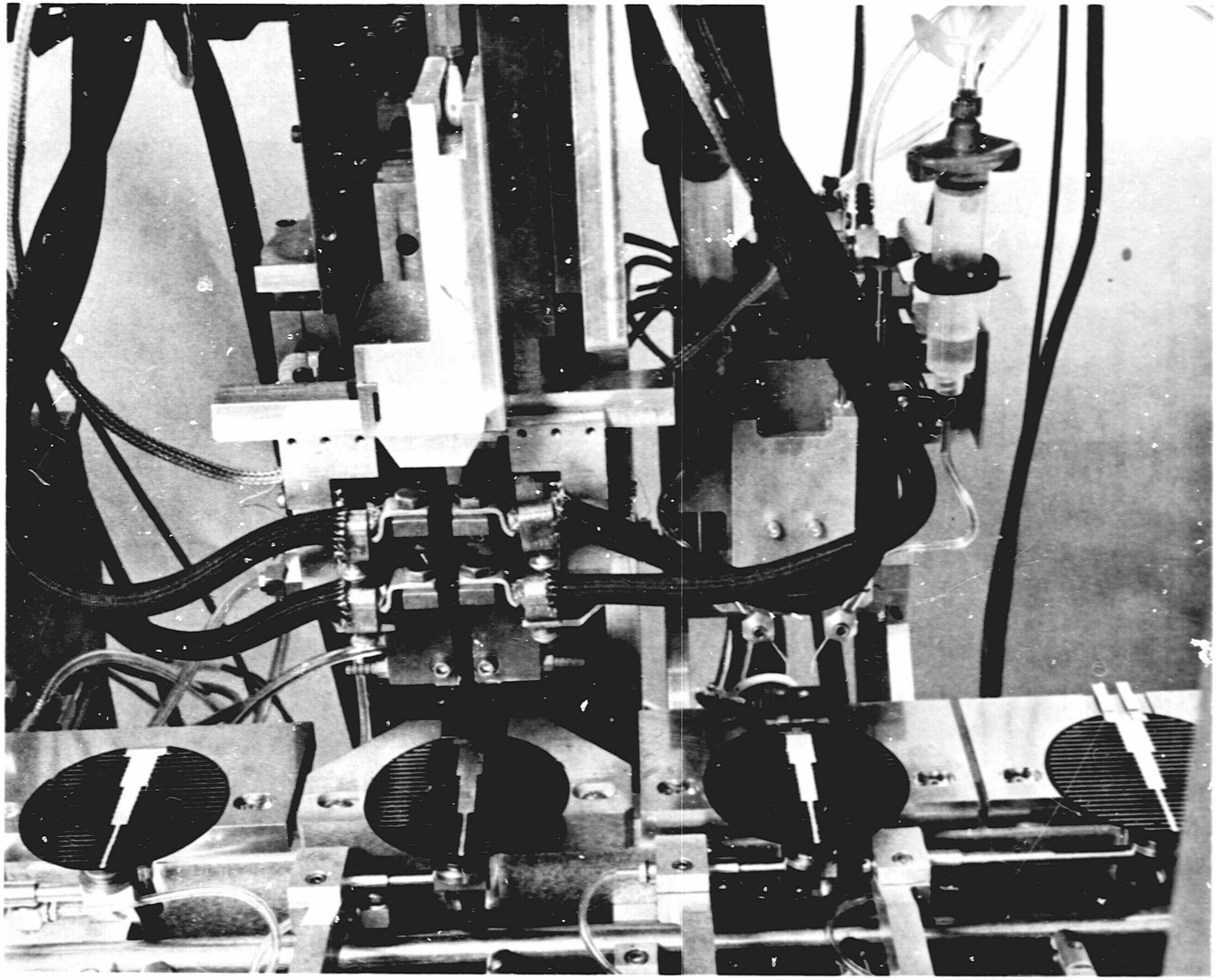


FIGURE 15 - FIRST INTERCONNECT (BOND) STATION

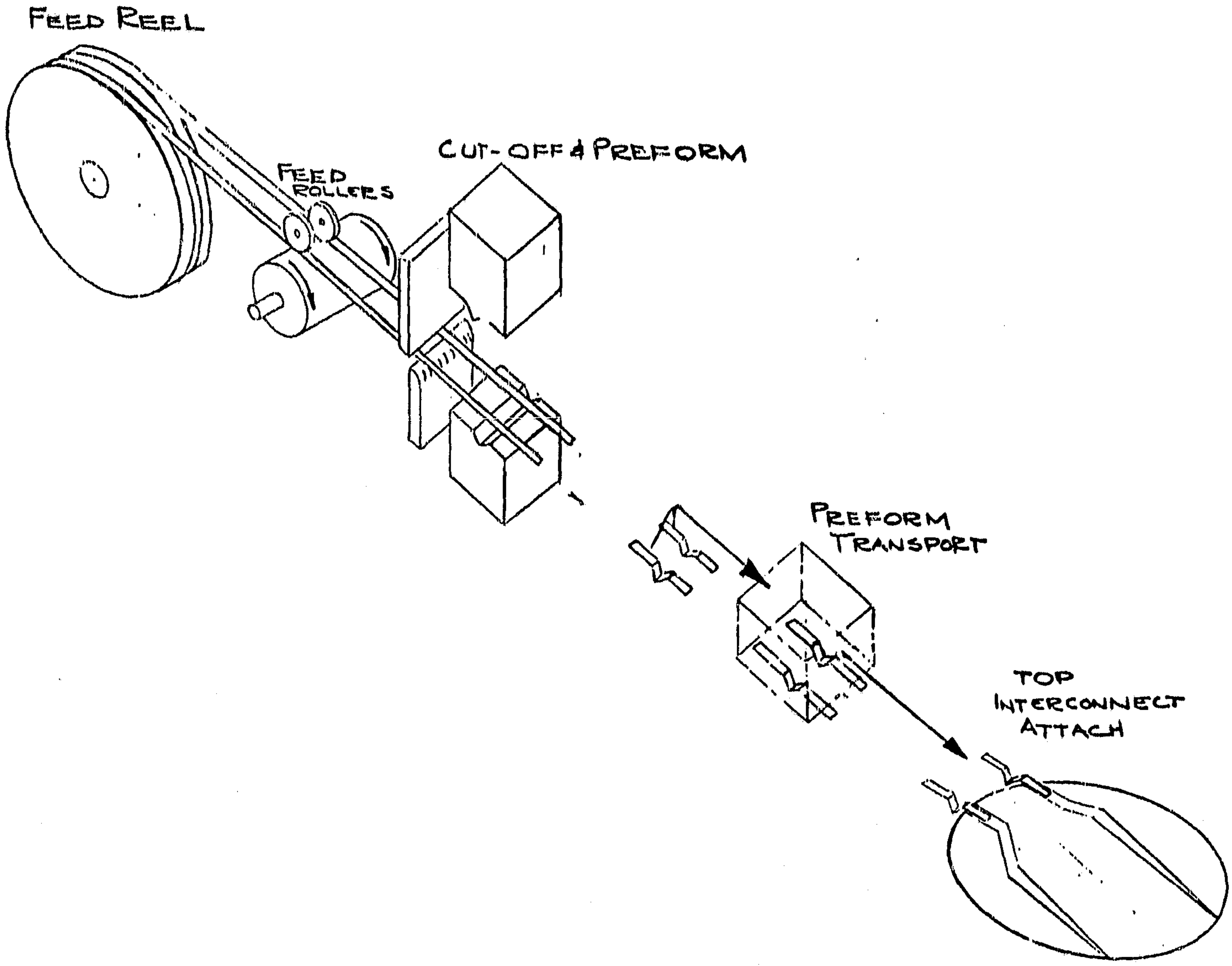


FIGURE 16 - FIRST INTERCONNECT STATION

The ribbon feed system at this station utilizes large reels of ribbon so as to minimize the necessity of frequent changes. This feed system is designed to accommodate a variety of widths and lengths of ribbon. The mechanism will feed, cut off and form the strain relief as part of the ribbon feed operation. The station is designed to feed and bond two ribbons per cell.

2.6.7 Flux Application for Second Interconnect (Figure 17)

After the cell is indexed into this station by walking beam conveyor, flux is applied to the tabs in preparation for accomplishing the stringing interconnects. This station is equipped with the same flux dispensing and control system as on Station Four.

2.6.8 Cell Inverting Station (Figure 18)

This station inverts the tabbed cell as it is transferred from the walking beam of the first half of the machine to the string conveyor of the second half of the machine. This station was added to the machine during the design and development stage. This decision was made because of several advantages it offered.

1. It minimizes contact on the sun (collector) side of the cell. The inverted cell can be picked up from the back surface and moved without engaging the collector surface underneath. This minimization of handling the cell on the sun side should result in less damage to collector surface, and thus maintain the cells electrical efficiency.

2. Inverting the cells also allows bonding of second interconnect from the top side. The bonding operation is then in the machine attendant's vision, making it easy to observe what is taking place. (See Figure 19). It also eliminates the possibility of solder running downward during the bonding operation.

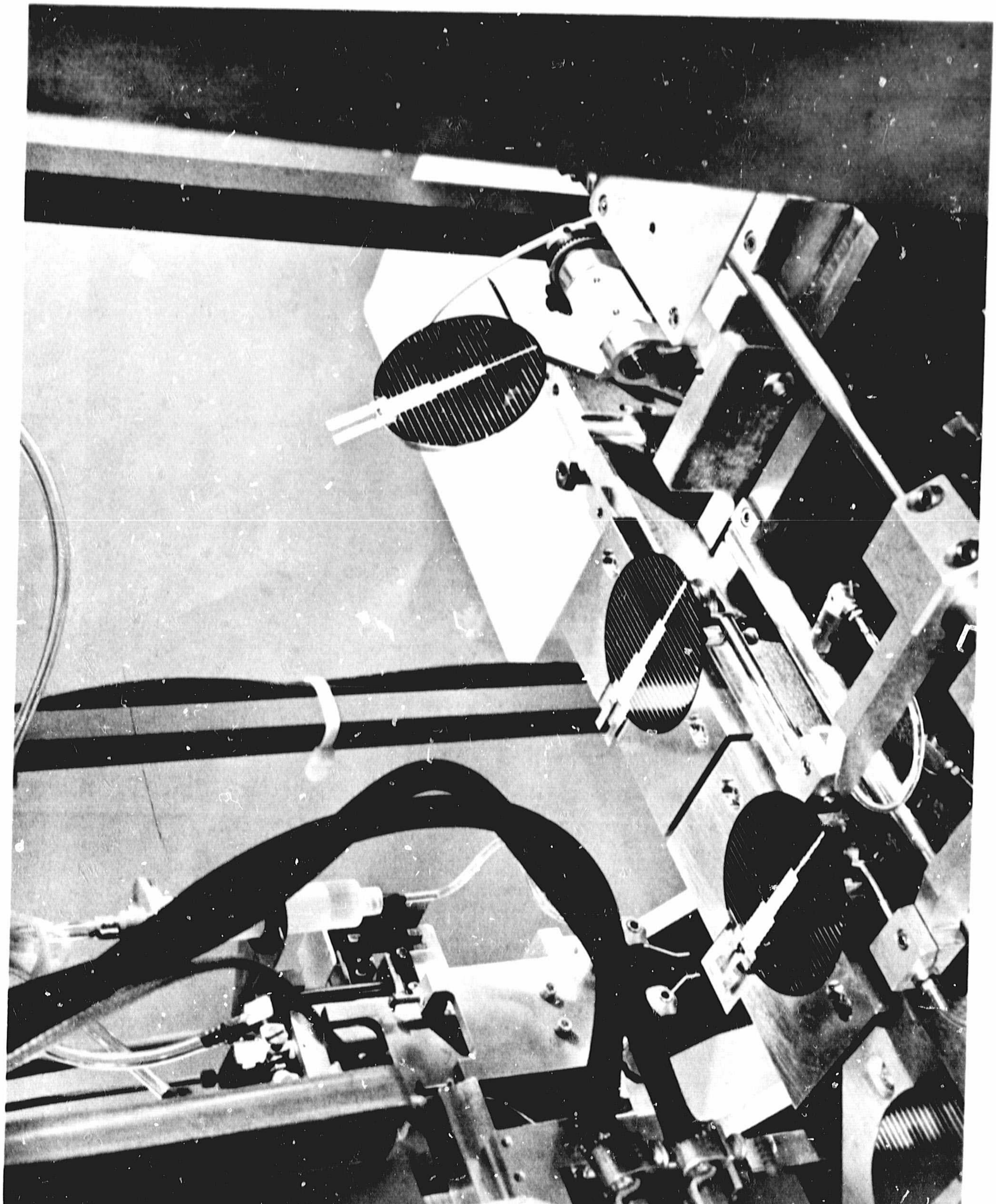


FIGURE 17 - SECOND FLUX AND CELL INVERTING STATIONS

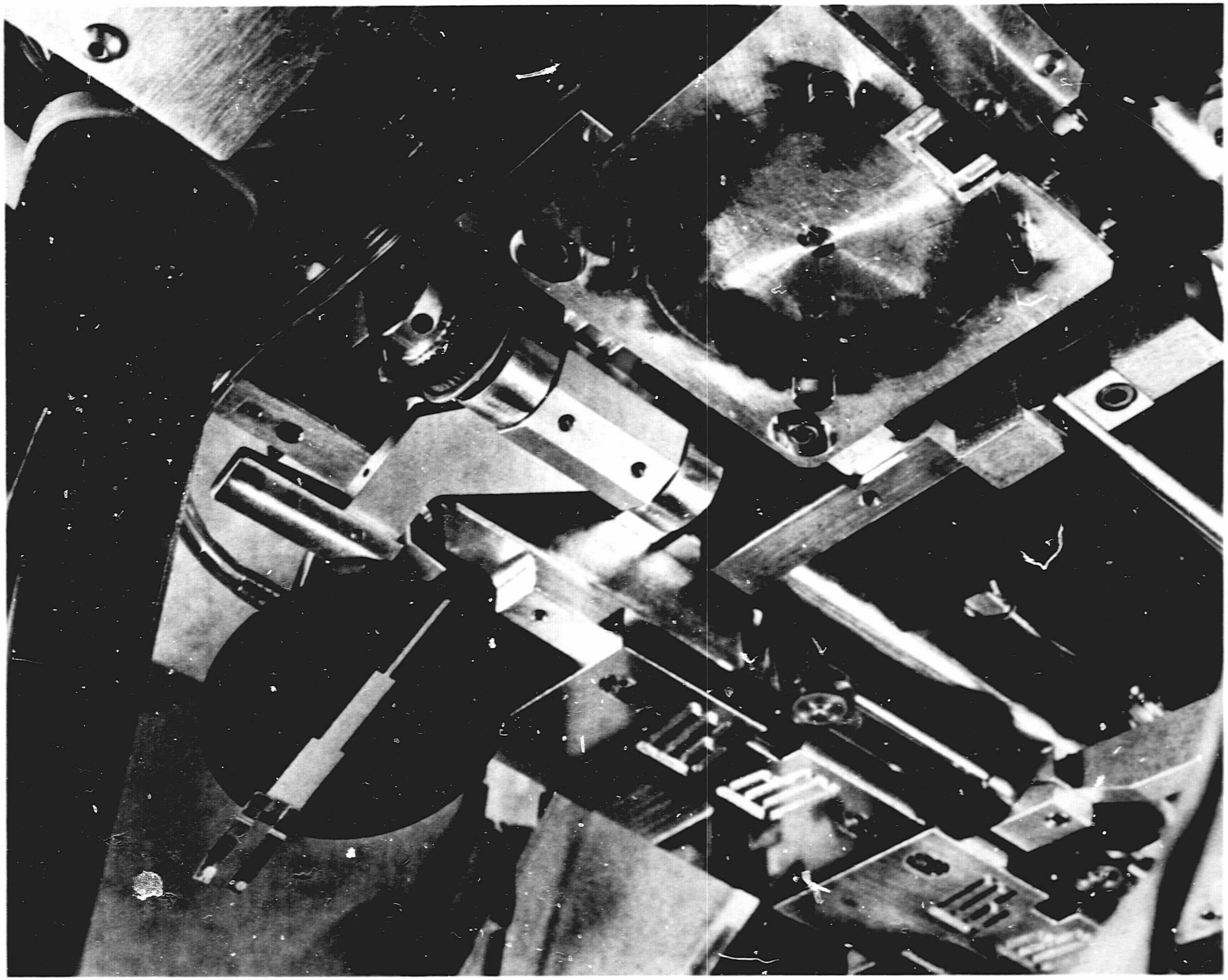


FIGURE 18 - CELL INVERTING STATION

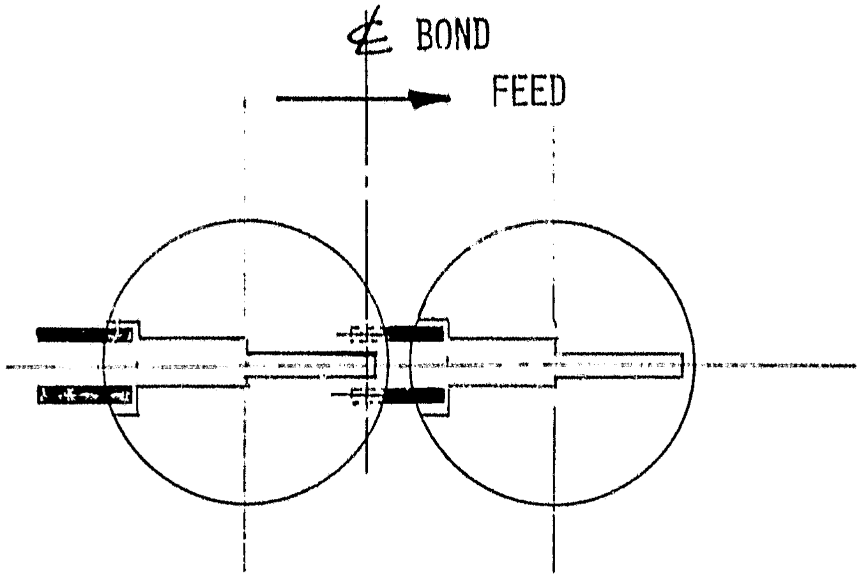


FIGURE 7a - Collector Side Up -
Bond takes place on underside of second cell

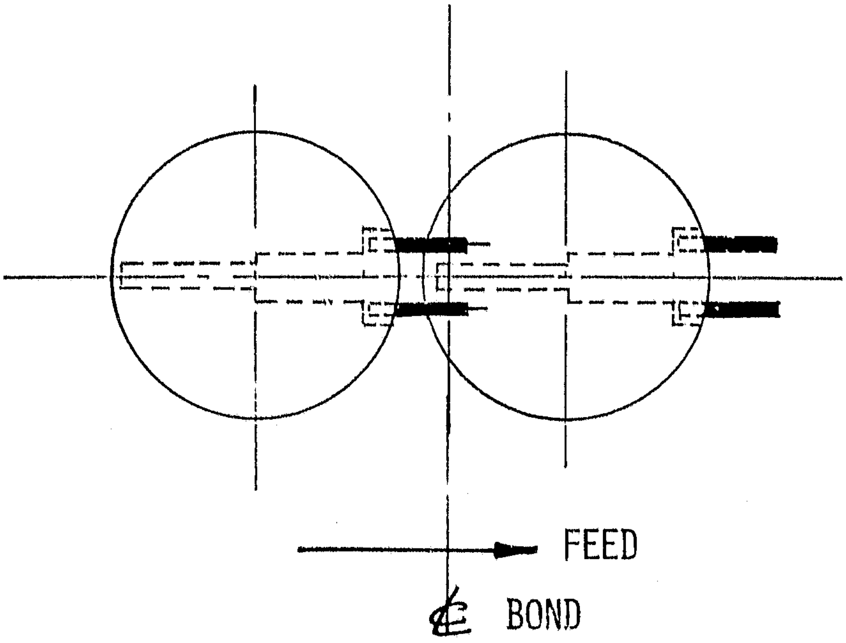


FIGURE 7b - Collector Side Down After Inversion of Cell -
Bond takes place on top side of first cell

FIGURE 19- SECOND INTERCONNECT STATION
COMPARISON OF BONDING WITH AND WITHOUT INVERSION OF CELL

3. Inverting the cells facilitates making string interconnections in the module array. If the strings were delivered to the module array with the collector side up, the connection from the end of one string to the beginning of another would have to be made under the first cell of the second string - away from the machine attendant. By inverting the cells the back side of the cell is exposed, making it easy to accomplish the soldering of one string to another.

The cell inversion mechanism deposits the tabbed cell on a "ready" stage where it is picked up by the transfer to string conveyor. The ready stage contains four (4) polished pins. (See Figure 18). These pins have a lead-in chamfer which tends to center the cell for more accurate positioning as it is entered in the string conveyor. The stage is machined so that cell rests only on its edge in order to minimize contact with the collector side of the cell. It also contains a sensor which signals the microprocessor control system that a cell has arrived at the ready stage. The control then automatically activates the next action.

2.6.9 Transfer to String Conveyor (Figure 20)

This station utilizes an indexing mechanism that picks up the tabbed cell from the ready stage of the cell inversion station and transfers it to the string conveyor without loss of orientation. The transfer system has a vacuum pick-up arm, similar to the walking beam conveyor system in the first half of the machine, which engages the cell on its back side.

The transfer system normally sits in a reset or "ready" position. As soon as the microprocessor controls signals that a solar cell has been delivered to the cell inversion receiving station, the transfer arm indexes over to pick the cell up and delivers it to the second interconnect bond station on the string conveyor, where it is joined into cell strings. When the vacuum pick-up arm delivers the cell to the second bond station, it holds the cell in position until the bonding action starts, at which time it returns to its reset position. This helps to maintain accuracy of cell position and uniformity of cell spacing in the formation of the cell string.

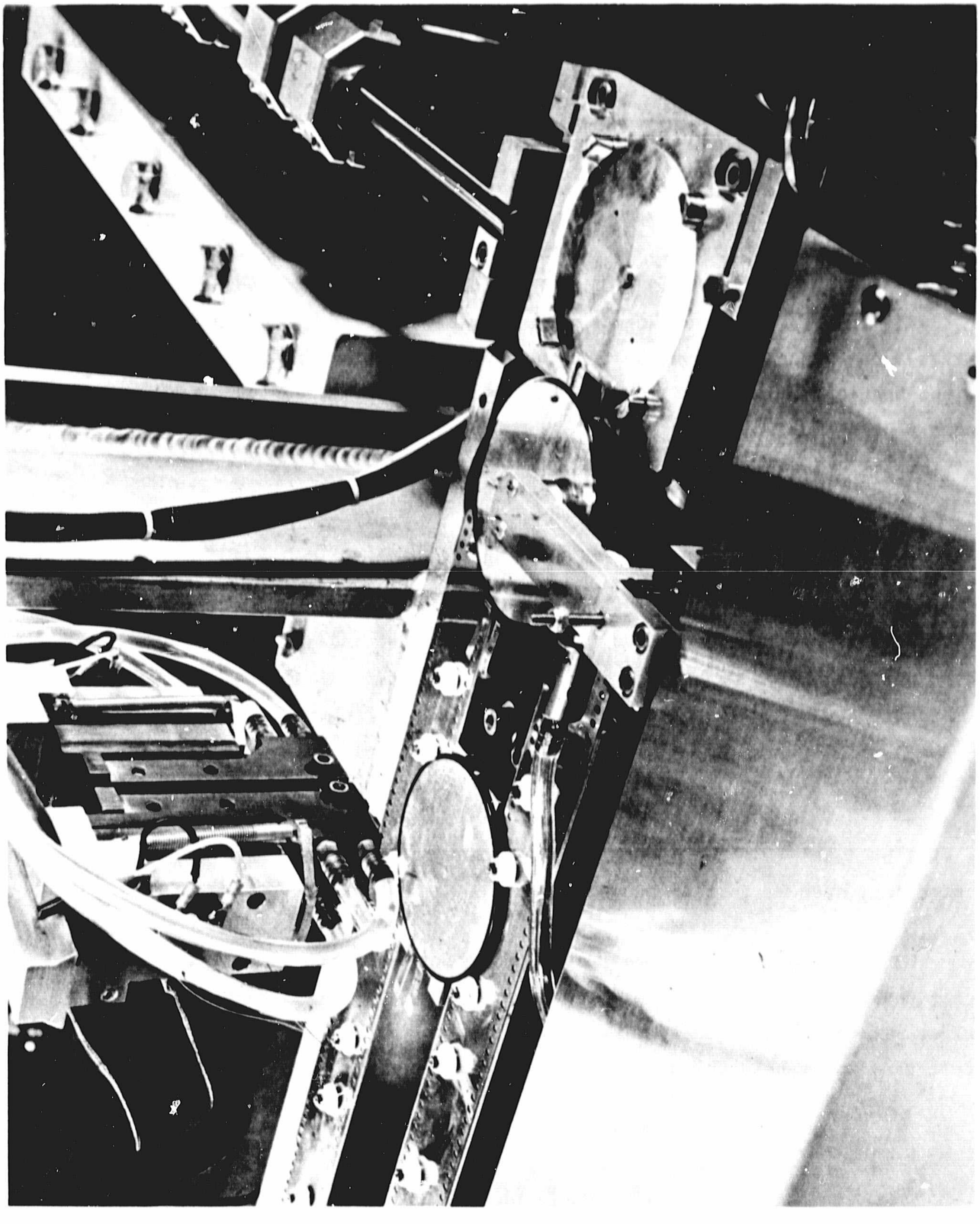


FIGURE 20 - TRANSFER TO STRING CONVEYOR

2.6.10 Second Interconnect Station (Figure 21)

This station performs the second or string interconnect bond operation. The bonding head, tools, and controls are the same as the first interconnect station. (See Section 2.6.6). Since the bond is performed on the back side of the cell, the settings may be slightly different than those for the first interconnect bond on the front side. As with the first bond station, the bonding tools are adjustable in X and Y direction, and each tool is water cooled and individually controlled for the bond parameters (temperature, time, force, etc.).

2.6.11 String Conveyor (Figure 22)

The string conveyor holds the location of the cells and maintains their intercell spacing and registration within each string. The positioning fixtures on the conveyor engage the cells on their edges only; thus minimizing any contact with the collector side of the cell. (See Figure 23)

The string conveyor is programmed to advance the cells one intercell pitch after the second interconnect is made. Upon completion of each string there will be a triple index to create a separation between strings for further handling, such as in the vacuum transfer system (See Section 2.6.13)

The string conveyor consists of two (2) metal belts with driving sprocket holes on a 35 mm spacing. They are driven by two (2) LaVezzi sprockets with teeth on same spacing . Metal belts were chosen because it was felt they would hold the accuracy requirements better. They would be

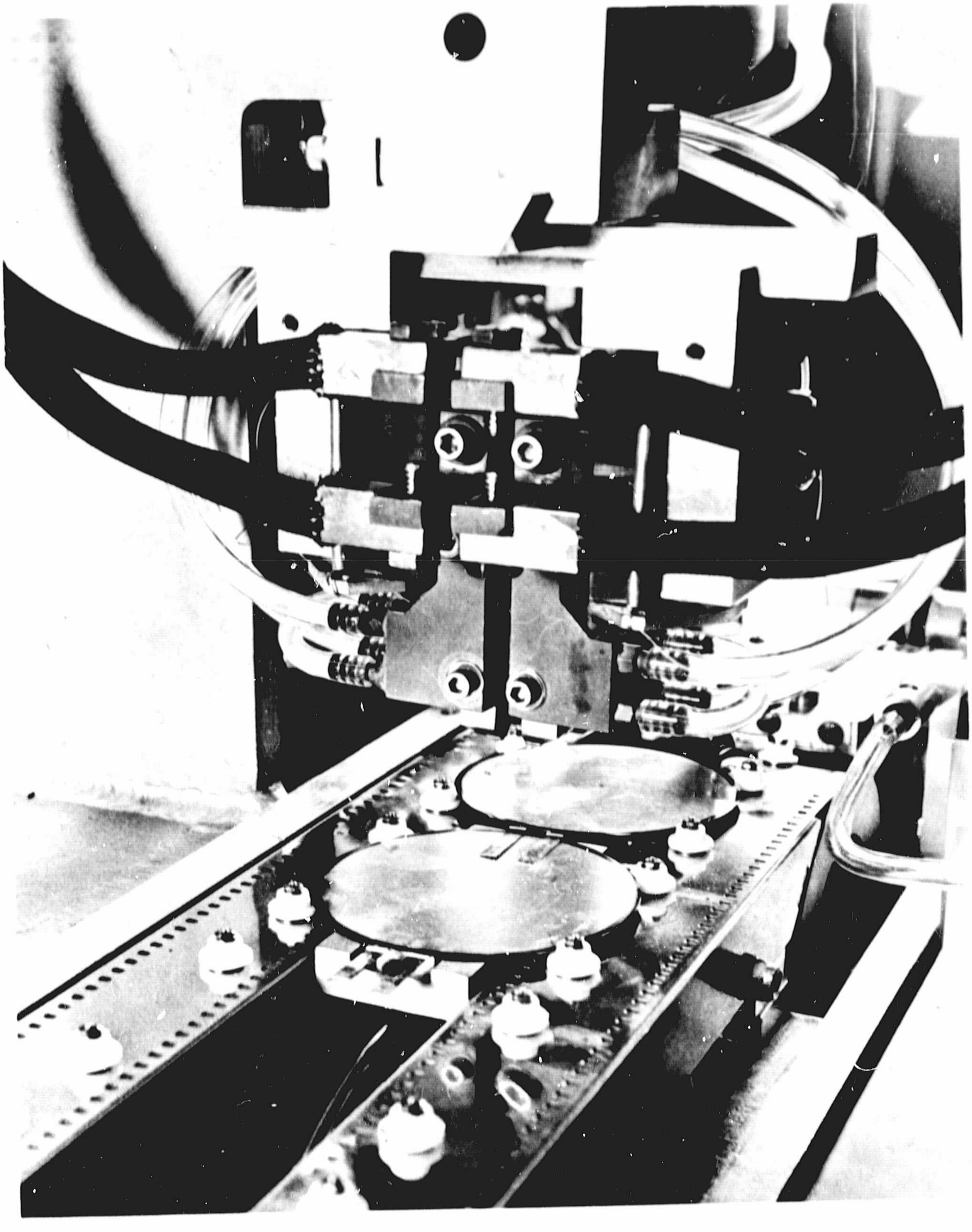


FIGURE 21 - SECOND INTERCONNECT STATION

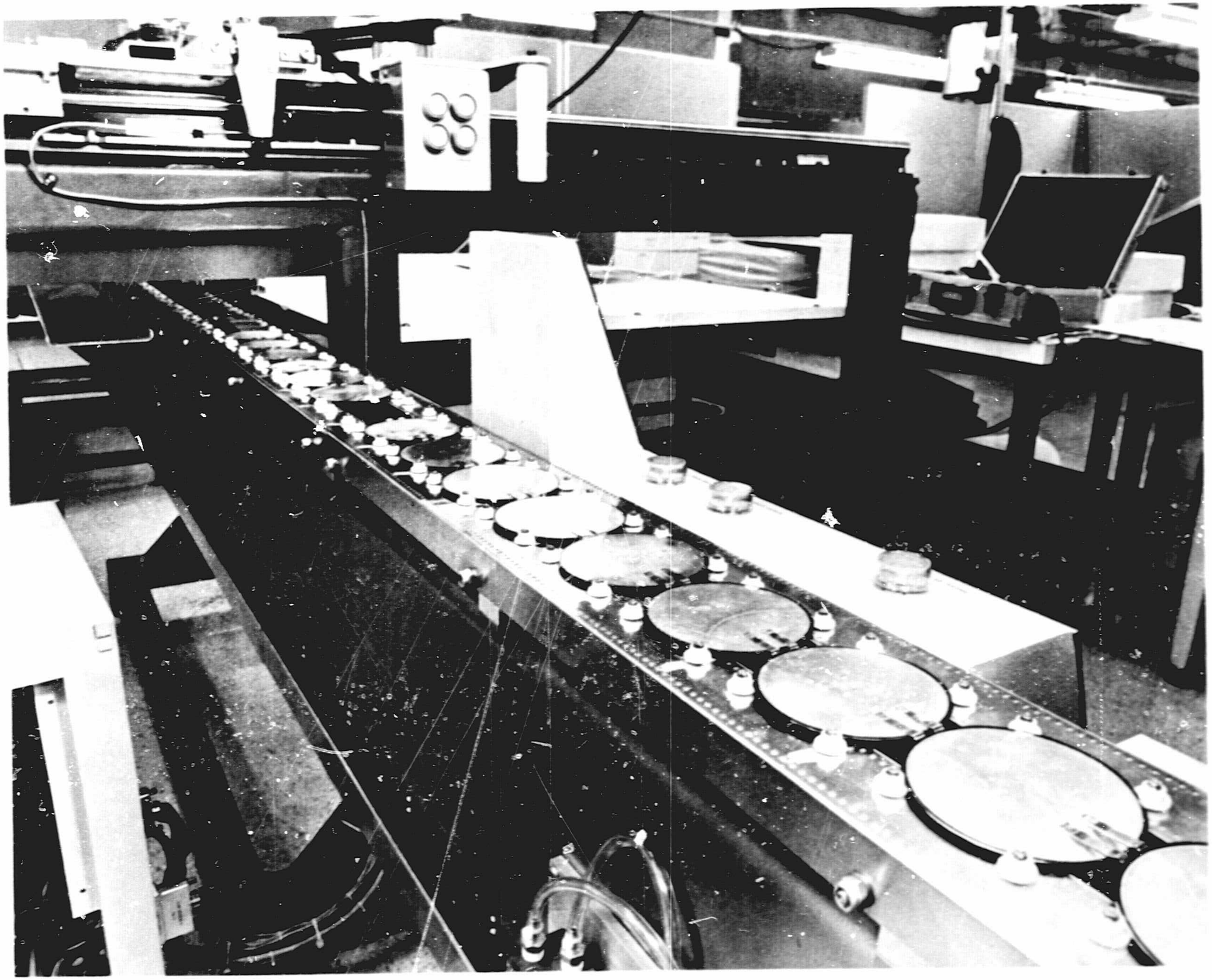


FIGURE 22 - STRING CONVEYOR

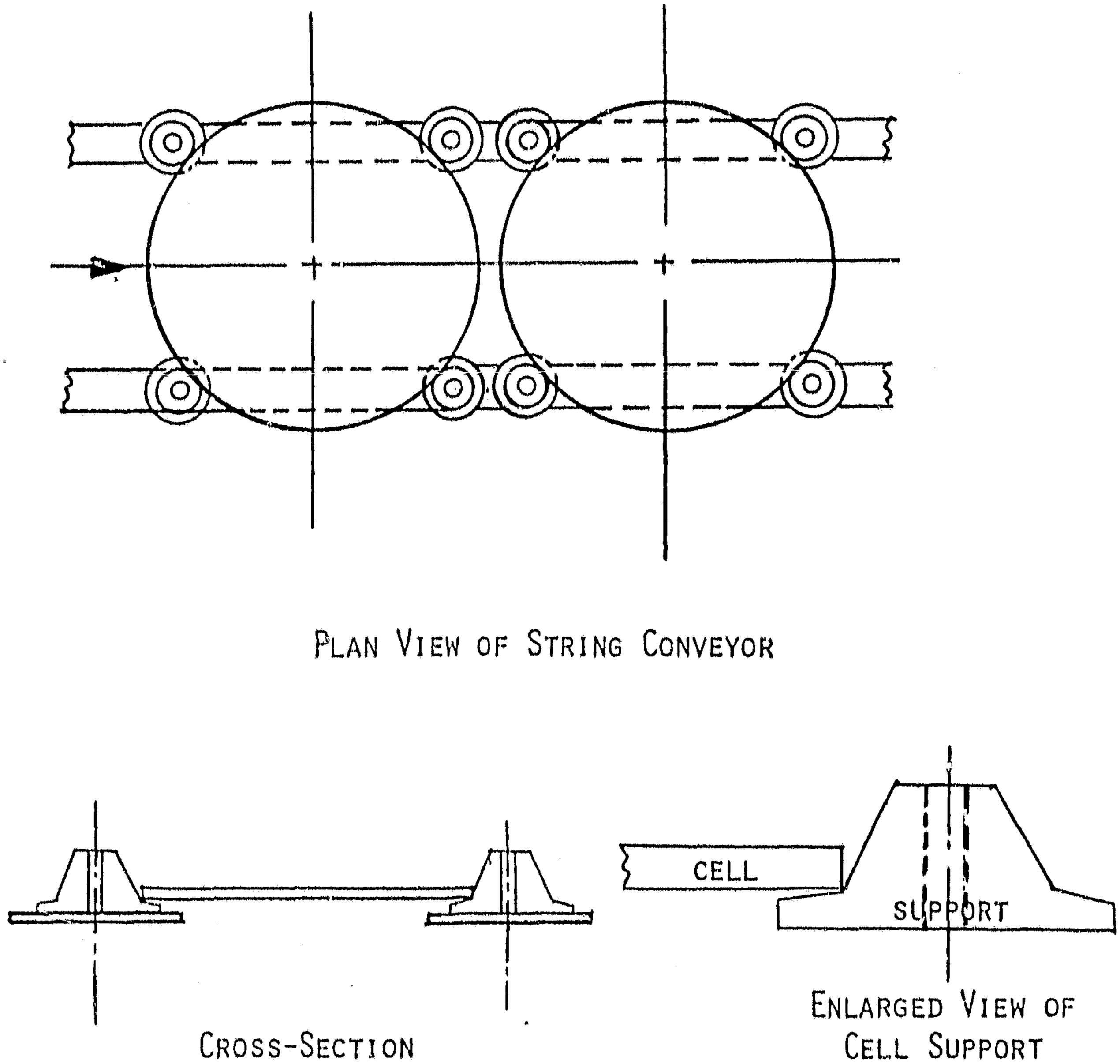


FIGURE 23 - STRING CONVEYOR

less affected by expansion and contraction due to ambient conditions. Also, they would not stretch as much, or experience material "creep", due to the tension set in the belt to eliminate any slack or play in the belts and any associated loss of accuracy in the advancement of the belt.

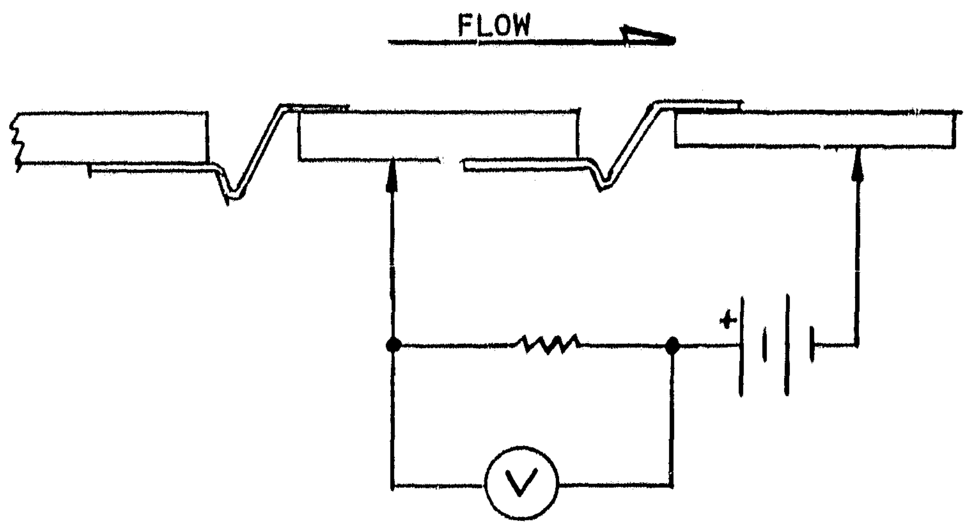
In addition, the belts have a small hole punched in each belt on the specified intercell pitch. It is this hole that engages the sensors in order to achieve the accurate advance and uniform string configuration that is desired.

A problem was encountered in that the LaVezzi sprockets had a tooth pitch of .186 inch while the belt had a sprocket hole pitch of .187 inch. This is due to the fact that the sprockets are designed for use in the film industry, and allows for shrinkage in the film strip. This does not occur in the steel belt used in the machine. As a result, the teeth of the sprocket were being shaved by the belt.

This problem was resolved by installing a tubular spacer, which results in the belt running around the sprocket at a greater pitch radius, making its traverse compatible with tooth pitch of the sprocket teeth.

2.6.12 Electrical Test Station (Optional)

If desired, an electrical test station can be incorporated in the string conveyor section between the second interconnect and the vacuum discharge area. (See Figure 24). There are several options; one could be electrical test of each cell pair after the second bond interconnect is made; another option would be to incorporate an electrical test of the entire string as soon as it has been completed. The machine can be programmed to initiate an end of string sequence in the case of any string or cell pair that has failed to pass the electrical test. The rejected string would then be placed in the reject station at the vacuum discharge area.



FORWARD BIAS TEST - AFTER EACH 2ND INTERCONNECT IS MADE

FIGURE 24 - STRING TEST

Originally, the machine was to contain an electrical test station to test each cell pair after the string interconnect was made. However, due to time and financial constraints this station was omitted from the machine.

There is some question as to whether such a station would be cost effective. Most solar module manufacturers incorporated an electrical test of the complete array just before encapsulation, after all the other operations were performed. With proper monitoring of the bond parameters, periodic off-line sampling, such as pull tests (non-destructive or destructive) and electrical tests, would achieve the same results. Since many manufacturers use these techniques anyway, the inclusion of any in-line test station would be included only at the user's option.

2.6.13 Vacuum Transfer to Module Array Area (Figure 25)

The string conveyor advances each string to the discharge end of the machine under the vacuum transfer system. A sensor detects when a string is in position to be picked up. When the sensor detects the end of the string, the vacuum lance is automatically actuated to descend and pick up the string. The vacuum lance is then moved manually on a track and the string is then placed into the module array area.

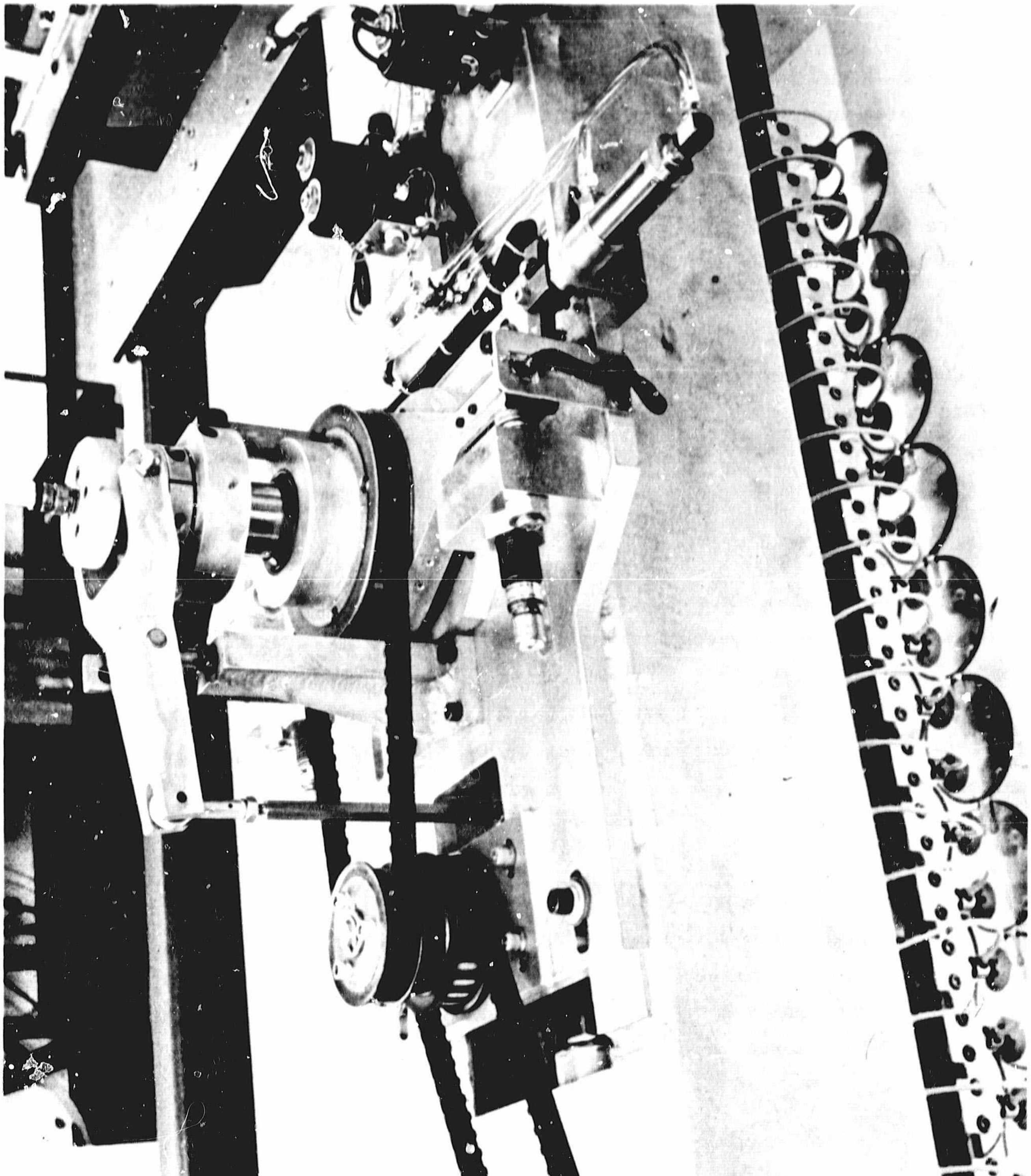


FIGURE 25 - VACUUM TRANSFER SY[illegible]

The vacuum lance contains two (2) vacuum pick-up cups for each cell. Each pick-up cup has its own vacuum system, generated by a positive air pressure venturi valve system. It can easily pick up a complete string or as few as two cells with all of the other vacuum pick-up cells exposed. (See Figure 26). Thus, the system does not have the problems of a loss of vacuum due to any openings in the system.

The vacuum lance maintains the proper intercell spacing of the strings due to the detents on the track. The vacuum frame is movable to these detented positions so that the cells can be placed accurately and repeatedly in the module array area up to a maximum size of 4 feet long and 2 feet in depth. (See Figure 27)

The vacuum lance is able to accomplish interdigitation of successive strings by being rotated 180° within the vacuum frame. This interdigitation will allow the machine to accomplish string reversals to accommodate any series or parallel arrangement of the strings in the module array. (See Figure 28). There is a reject station onto which the vacuum lance can deposit any string that is determined to require rework. This can be done visually as well as through automatic programming in conjunction with electric tests previously discussed.

The vacuum lance which operates manually in this machine can be motorized if desired. However, this would be determined by the specific customer appliation and whether it would be cost effective. We have found that the operator normally has sufficient time to accomplish the placement of the string in the module array area during the normal production cycle of the machine.

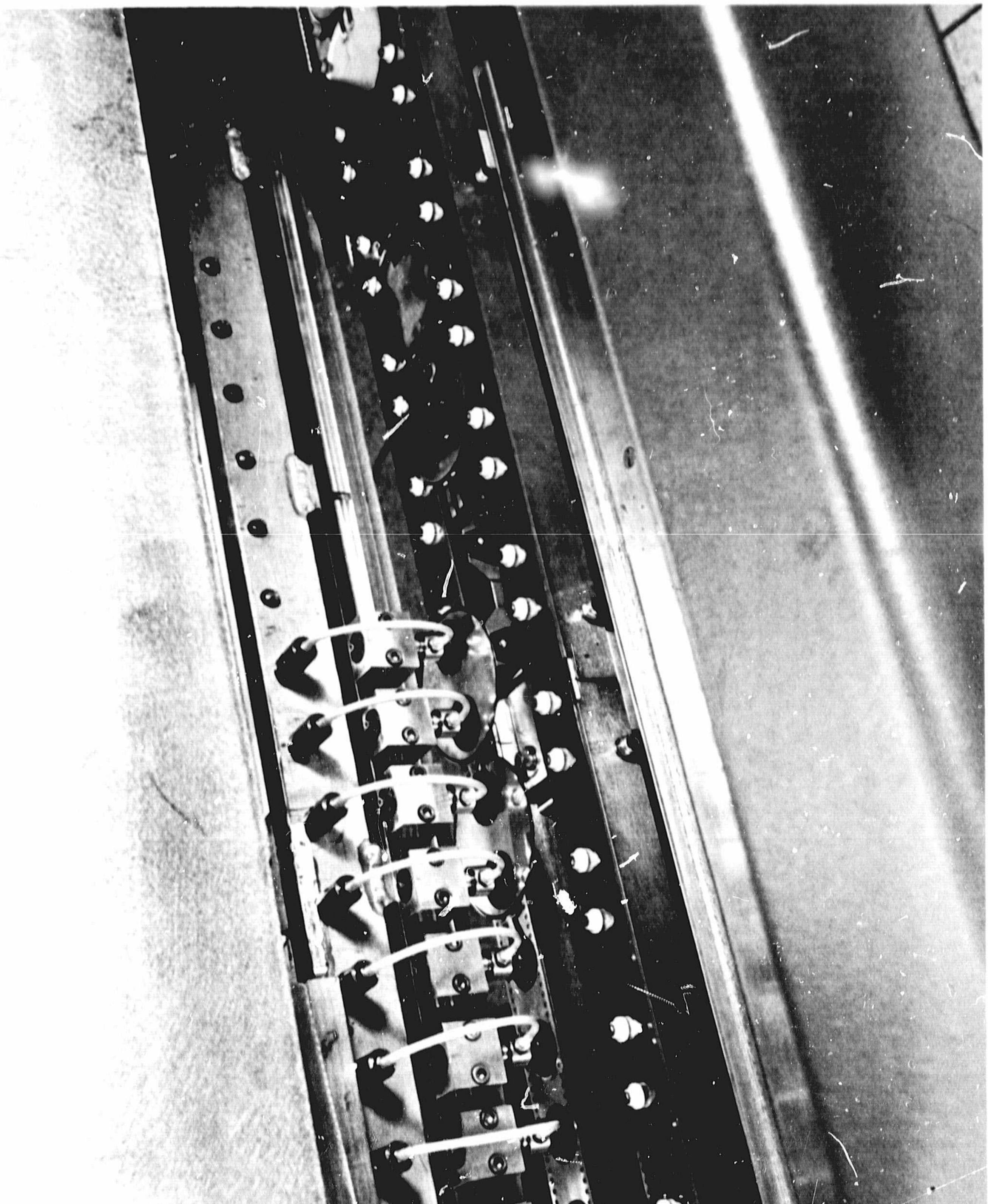


FIGURE 26 - VACUUM LANCE - SHOWING VACUUM PICK-UP OF TWO SOLAR CELLS - MINIMUM PARTIAL STRING

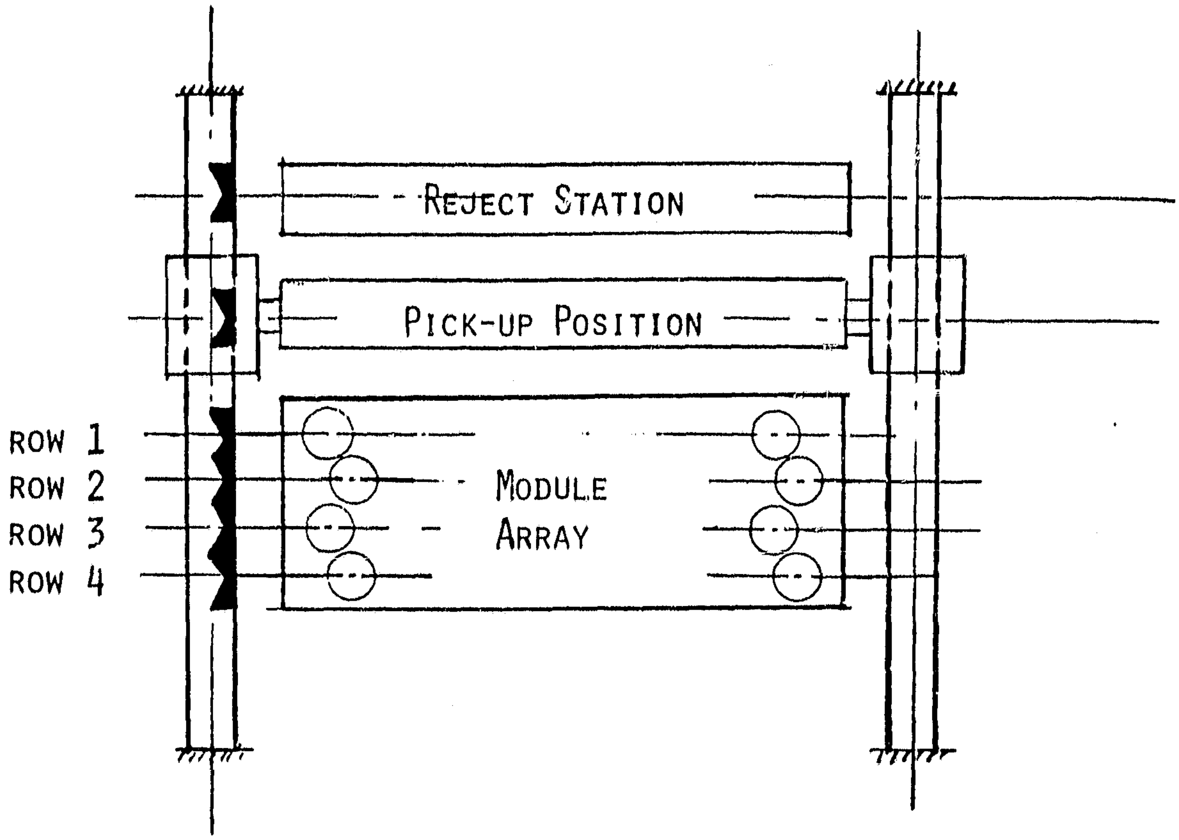


FIGURE 27 - VACUUM TRANSFER SYSTEM DETENT POSITIONS

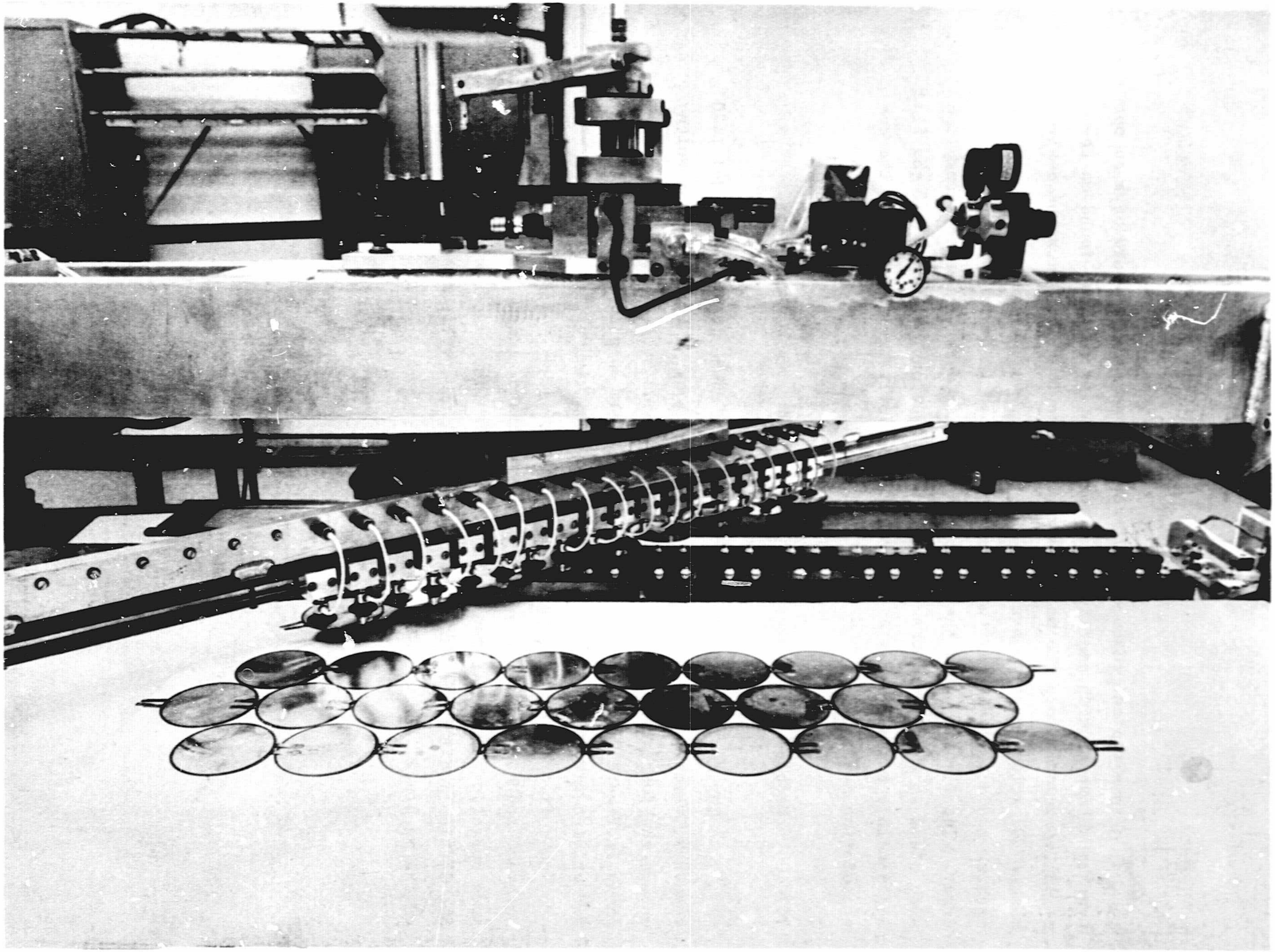
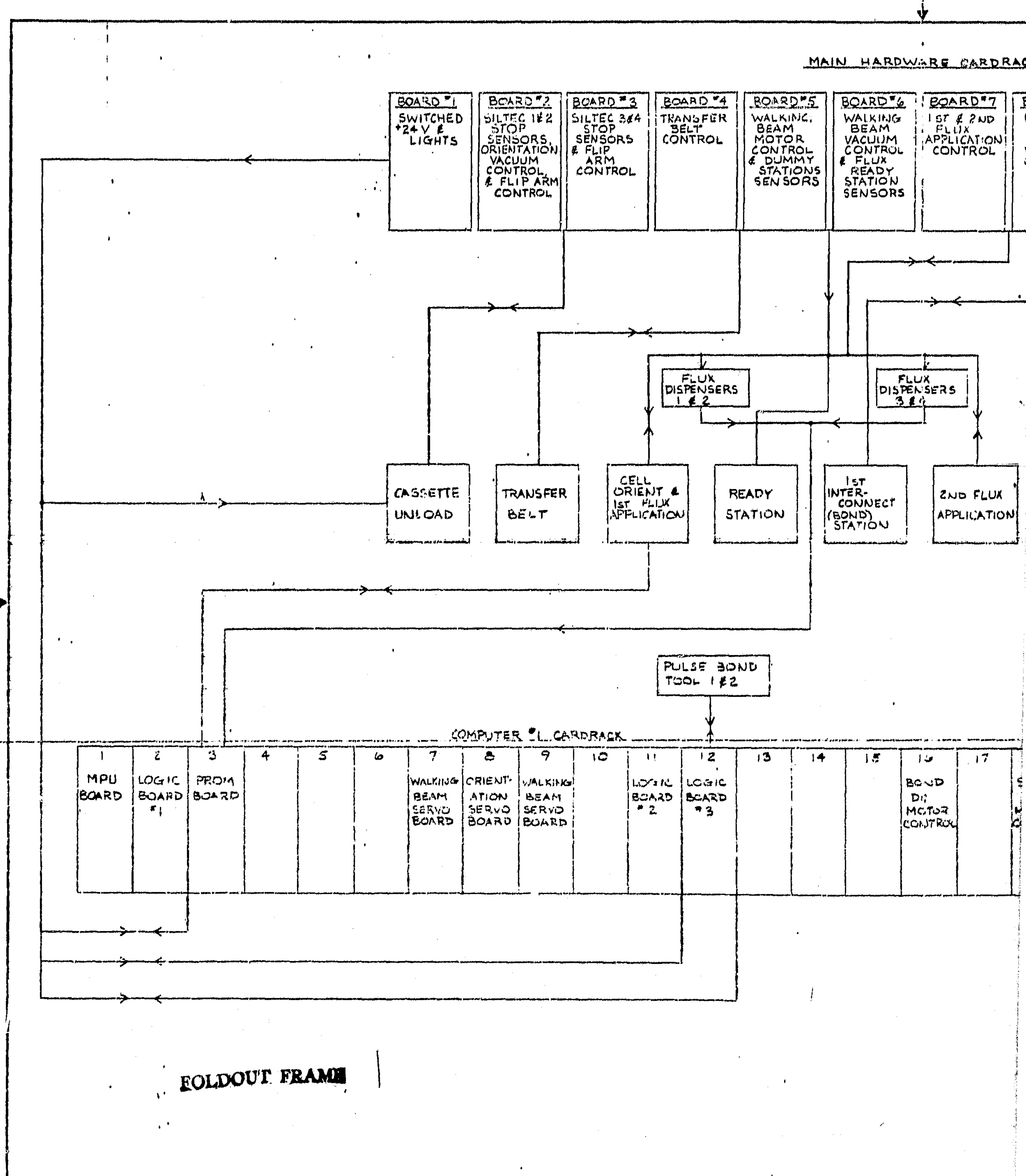


FIGURE 28 - VACUUM TRANSFER SYSTEM - INTERDIGITATION AND STRING REVERSAL

In a typical customer application, the machine would have an open-type work fixture with positioning sleeves similar to those found on the string conveyor. Once the module array fixture is filled with the desired number and arrangement of strings, the fixture would be removed from the machine and a new empty fixture would be entered in for the next module array. The fixture would then be taken to other workbenches to accomplish such steps as completing the interstring connections, cleaning off the flux and possibly a final array electrical test prior to being taken to the encapsulation station.

2.7 Machine Microprocessor Control System

The control system utilized in the machine is the K&S Model 1470 computer, which was modified for this application. A block diagram which covers the functions of the first half and second half of the machine are shown in Figure 29. Figures 30, 31, 32, 33, and 34 show the control panels, and printed circuit board card racks associated with each section of the machine. Figure 35 shows the flow chart of the mode control of the machine. Software and hardware development was accomplished in conjunction with each mode operation and the sequence of events that take place in each station. See Section 2.8.1 for a further description of the various operating modes of the machine.



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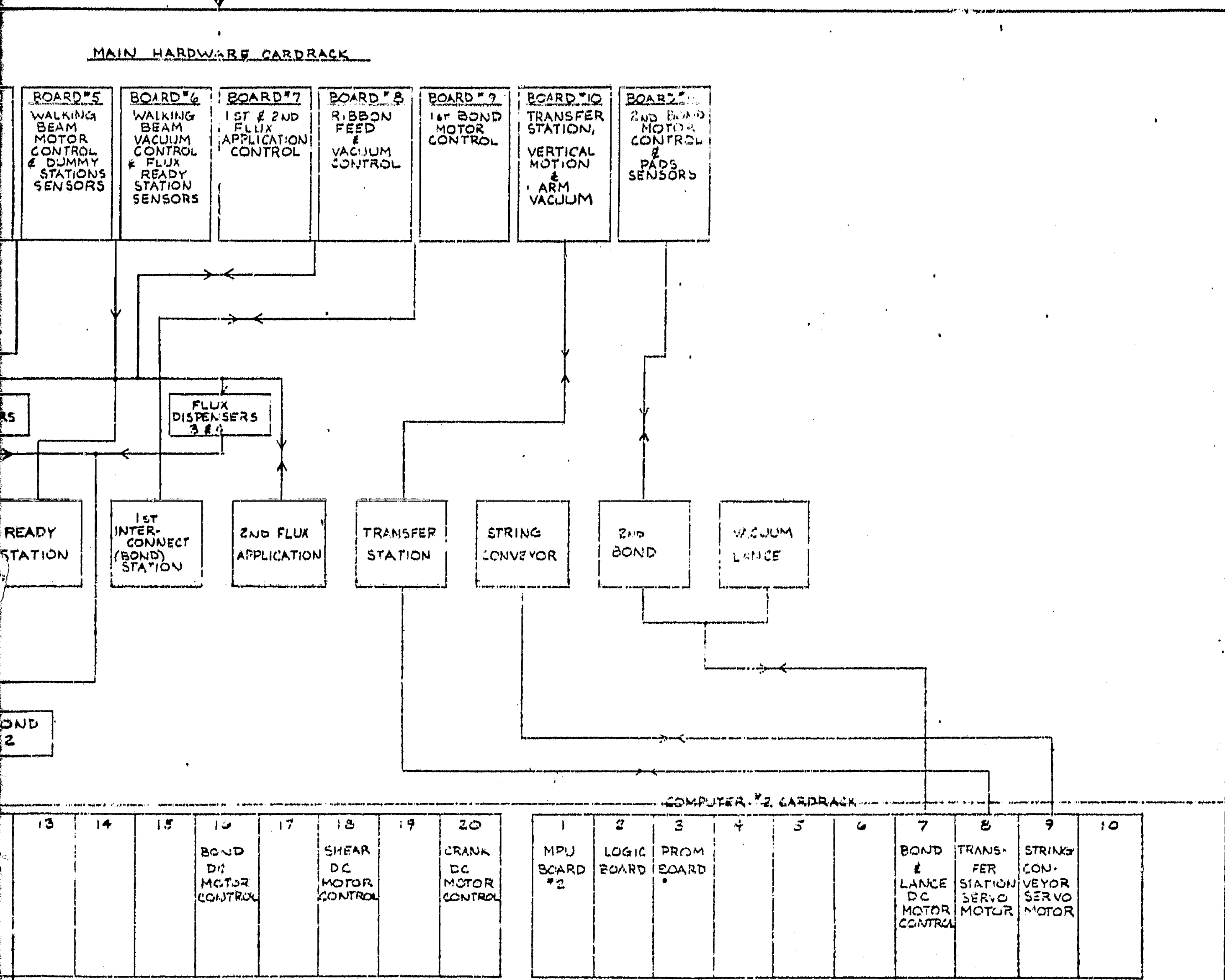

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FIGURE 29 - BLOCK DIAGRAM

PART NAME: BLOCK DIAGRAM
PRODUCT: 9001
KULICKE & SOFFA INDUSTRIES, INC.

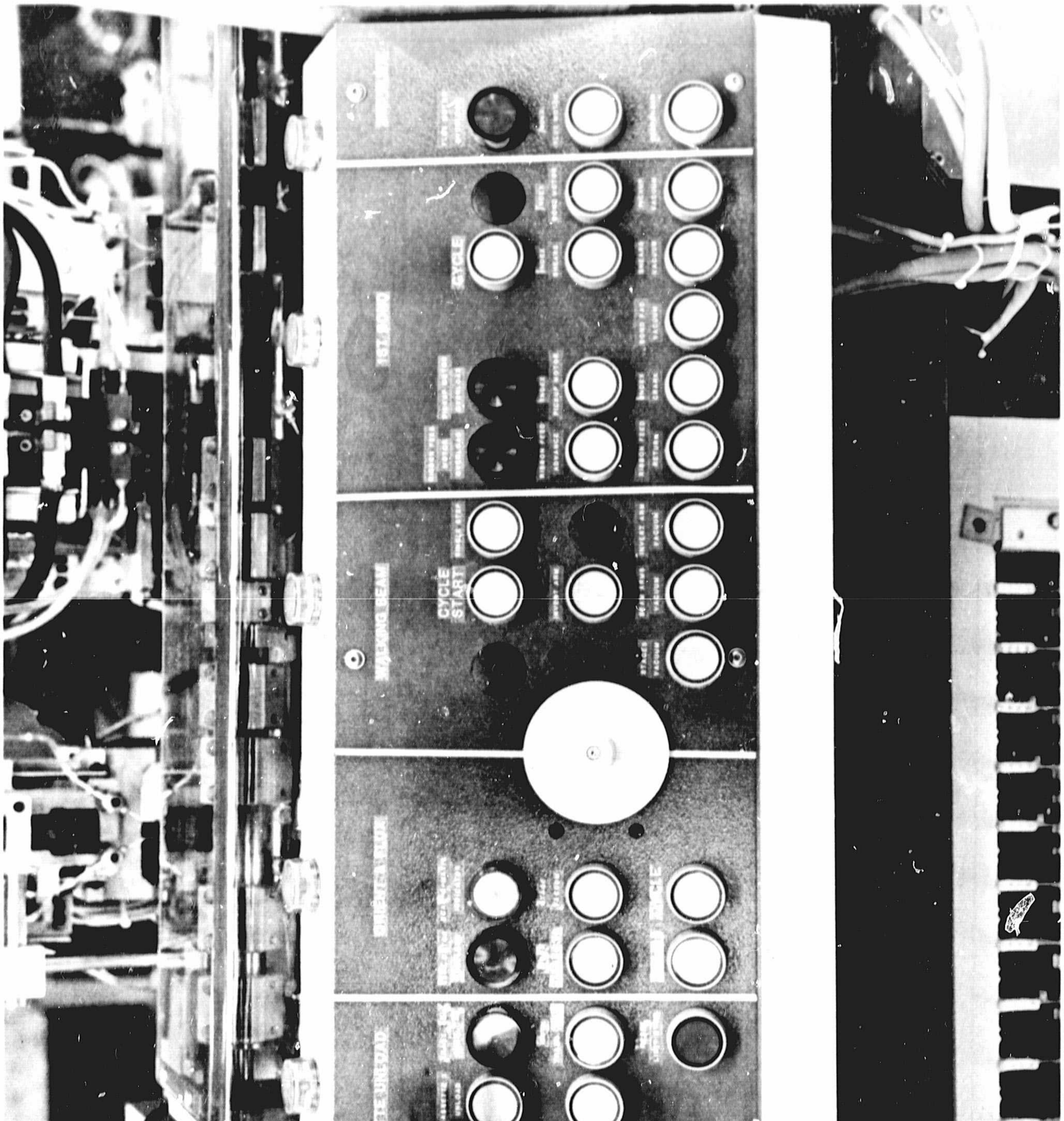

FIGURE 30 - CONTROL PANEL - FIRST HALF OF MACHINE

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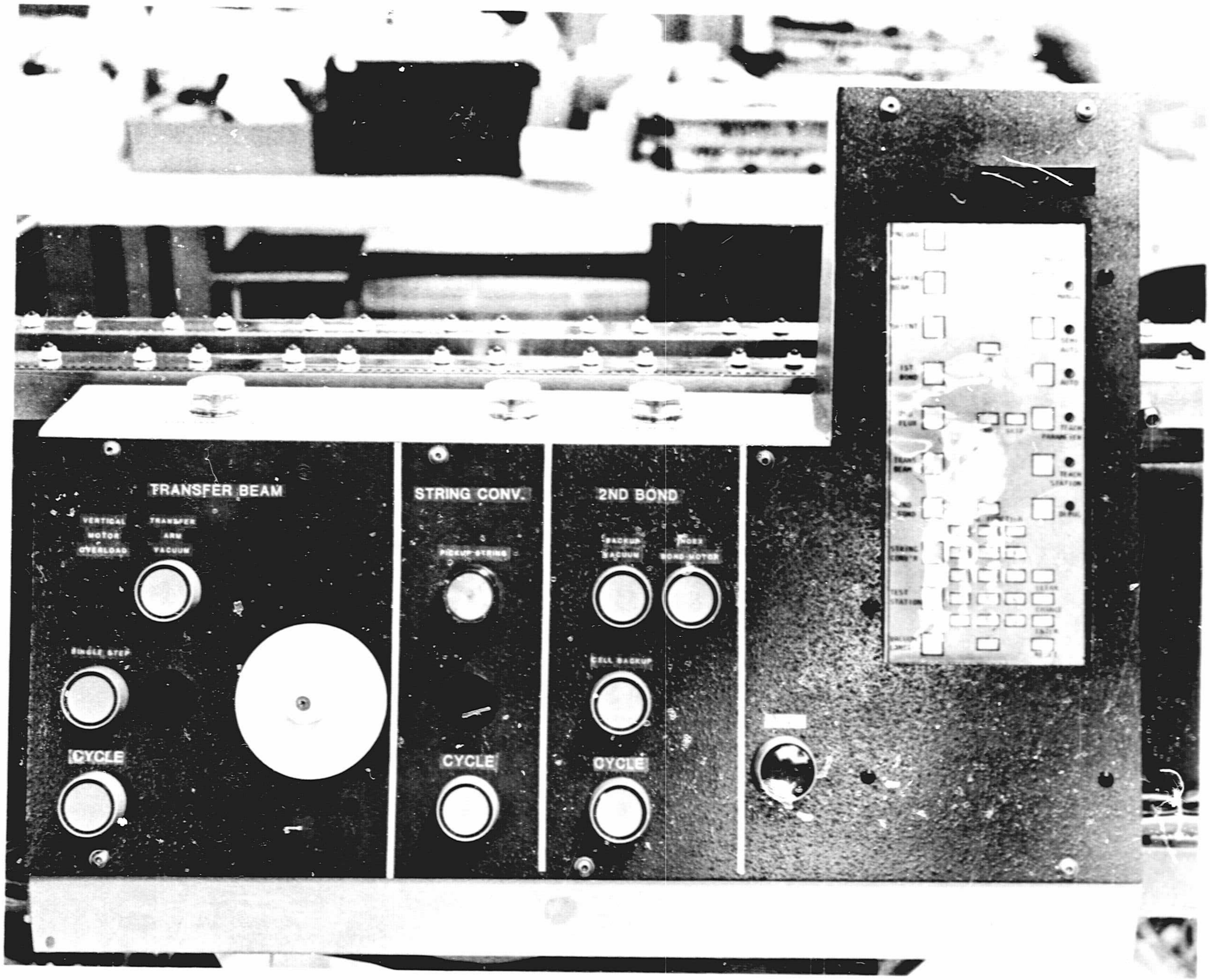


FIGURE 31 - KEYBOARD AND CONTROL PANEL - SECOND HALF OF MACHINE

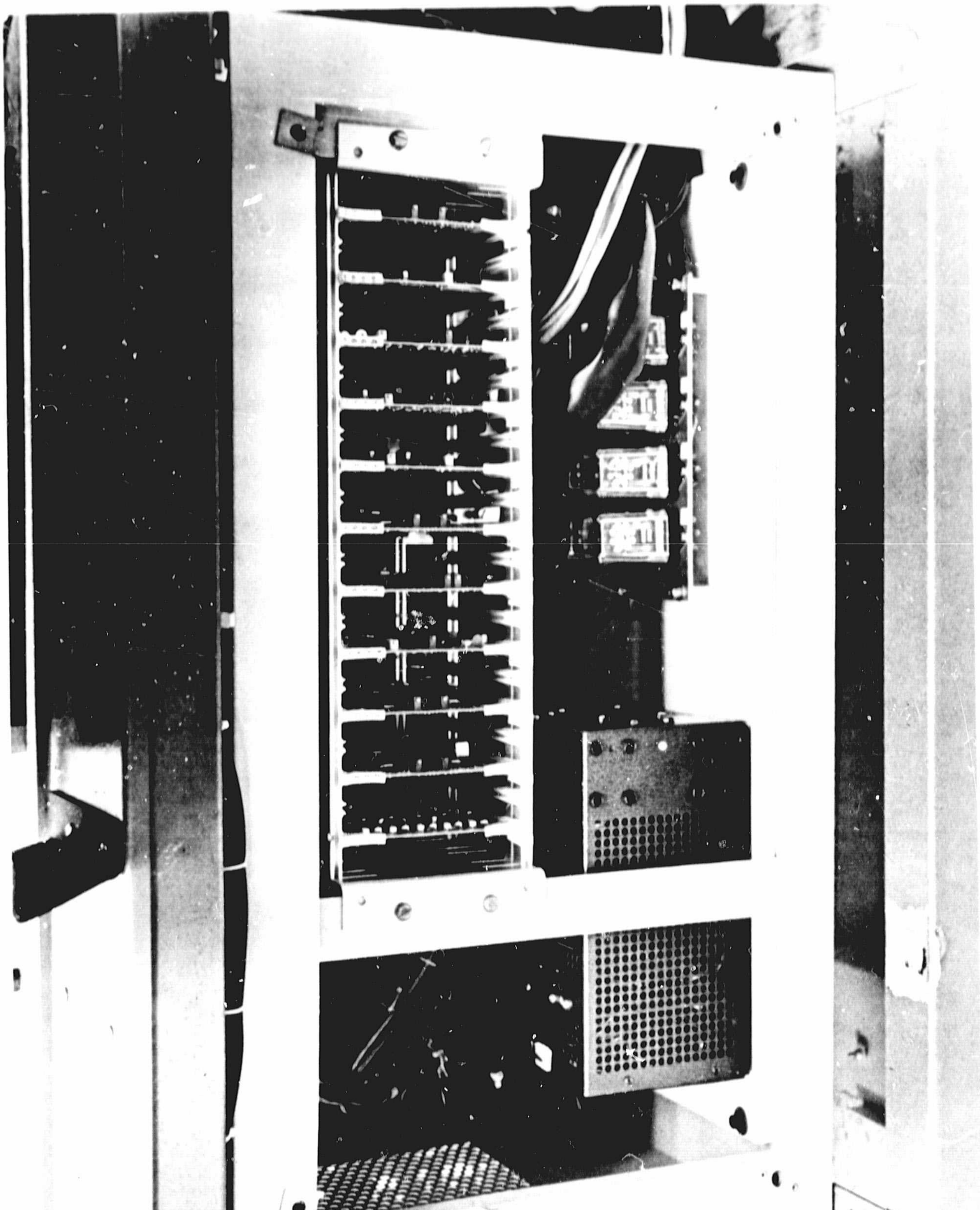


FIGURE 32 - PRINTED CIRCUIT BOARD CARD RACK - FIRST HALF OF MACHINE

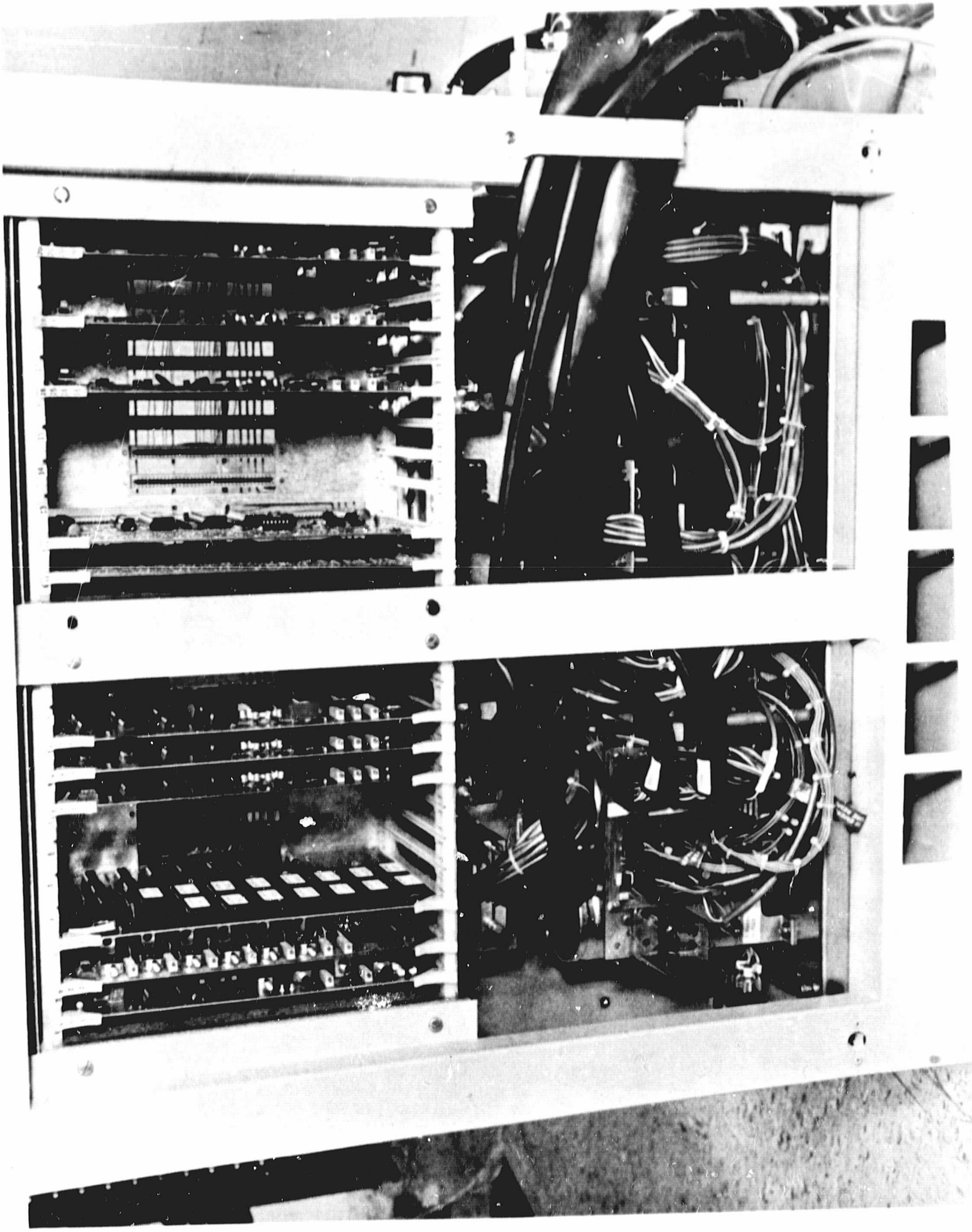


FIGURE 33 - COMPUTER NO. 1 CARD RACK

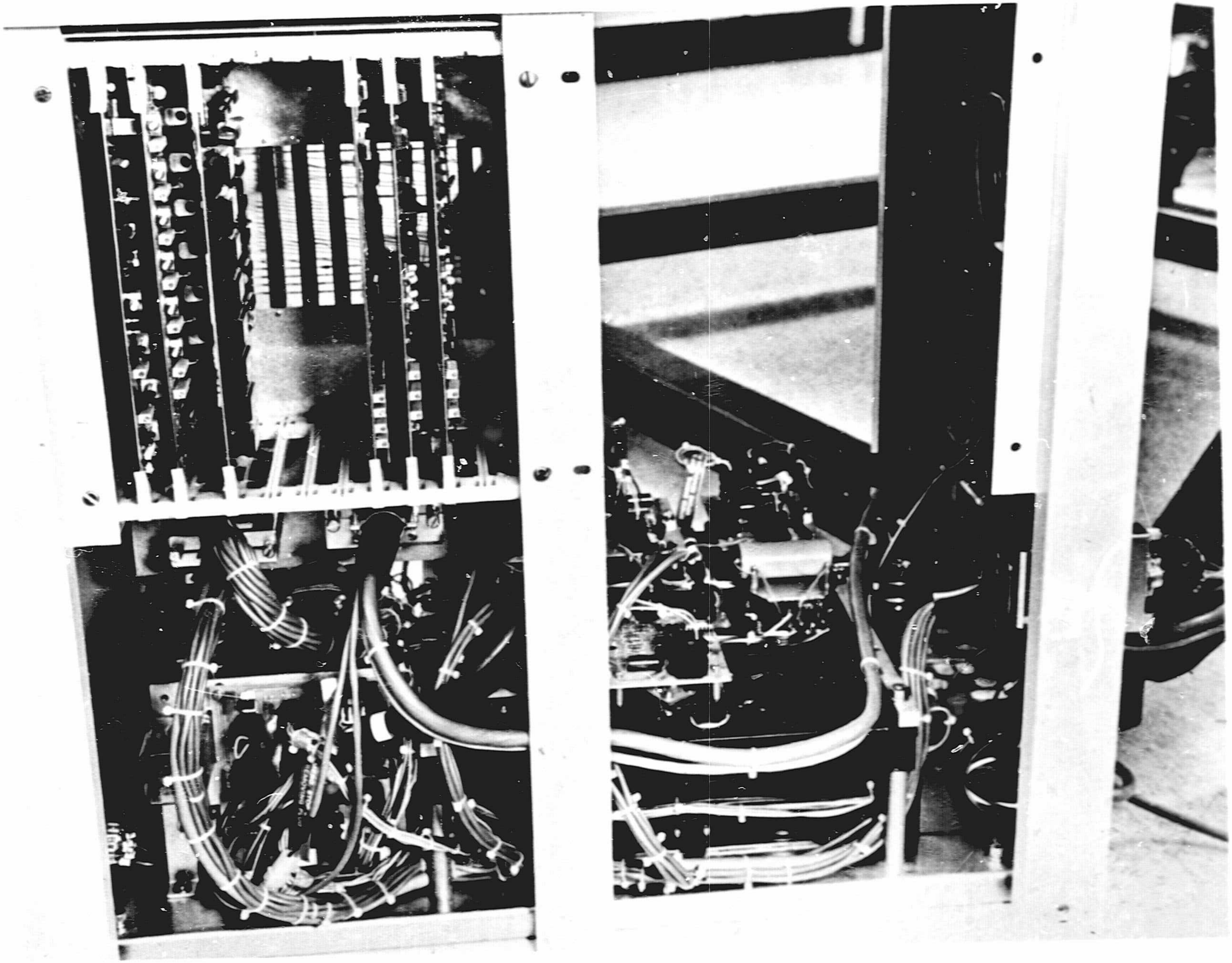
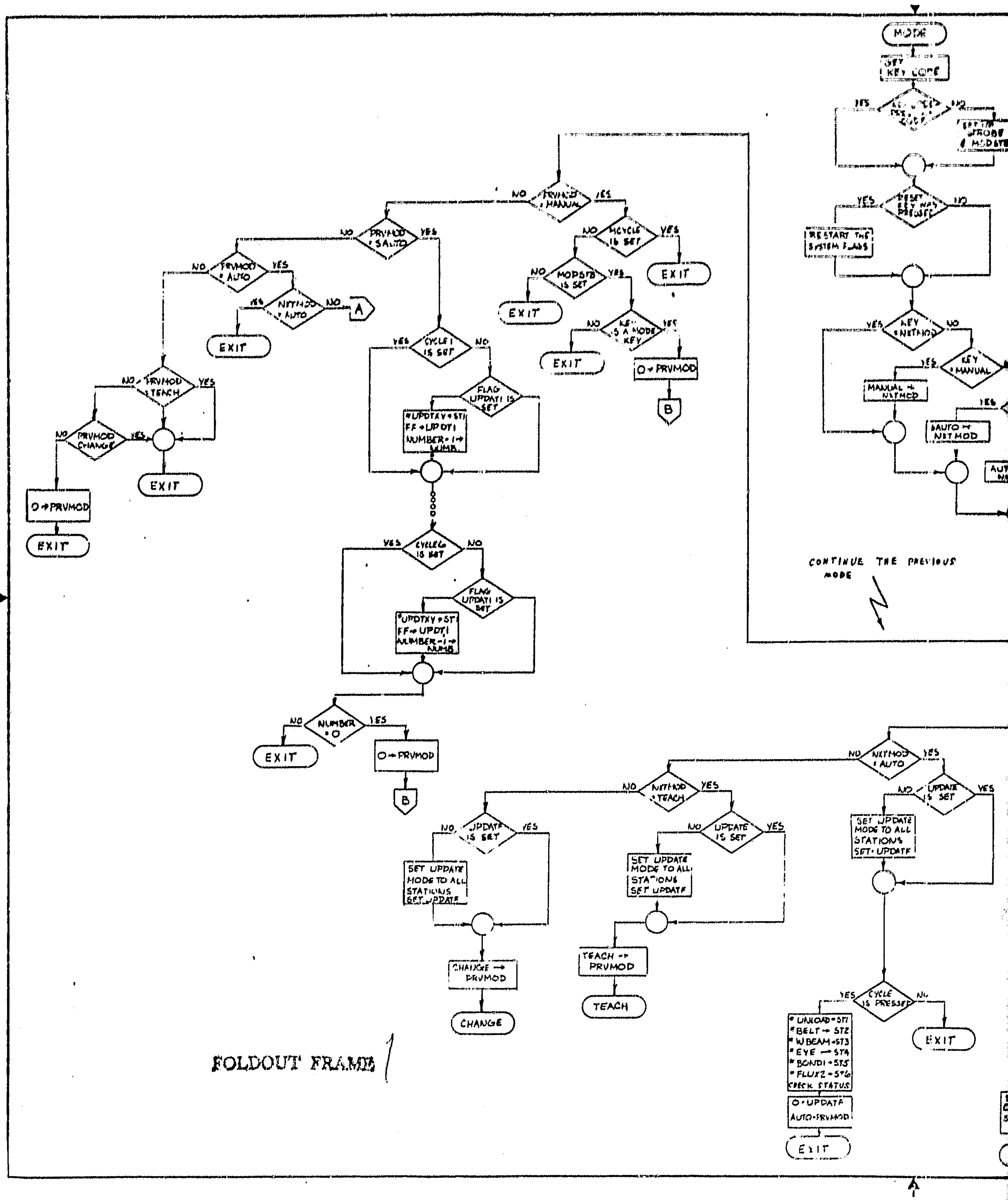


FIGURE 34 - COMPUTER NO. 2 CARD RACK



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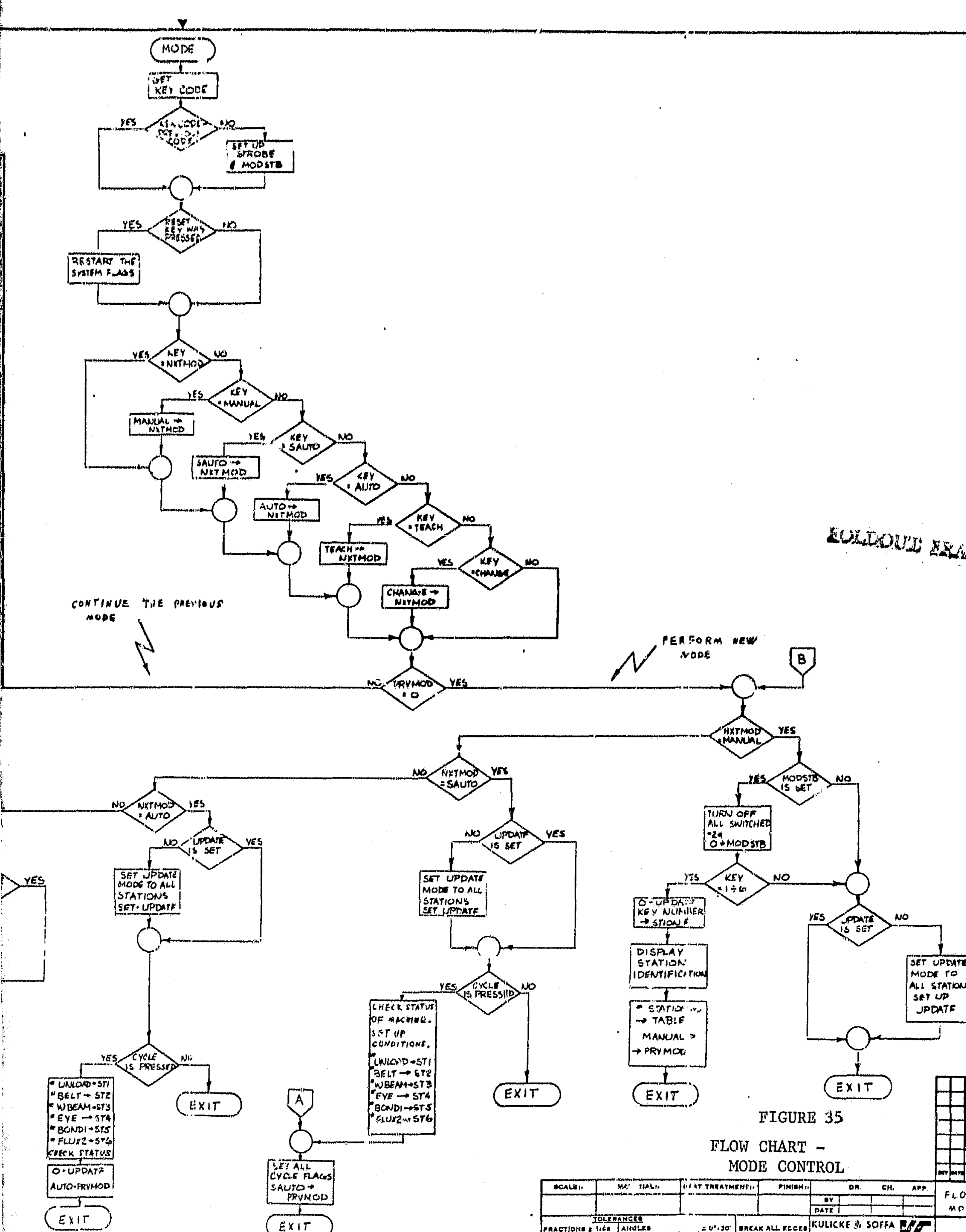


FIGURE 35

FLOW CHART - MODE CONTROL

SCALE:	MATERIAL:	HEAT TREATMENT:	FINISH:	DR.	CH.	APP.
TOLERANCES: FRACTIONS ± 1/64, DECIMALS ± .005, ANGLES ± 0°-30', SURFACE FINISH, BREAK ALL EDGES APPROX. 1/64 X 45°, UNLESS OTHERWISE SPECIFIED			KULICKE & SOFFA INDUSTRIES, INC.			

PART NAME	PRODUCT
FLOW CHART MODE CONTROL	E-1001
PART NO. 9001-5023-0	

2.8 Operation of Machine

2.8.1 Modes of Operation

The machine can be operated in the following modes:

a. Teach
b. Manual
c. Semi-Automatic
d. Automatic

All modes of operation are initiated by depressing keys located on the keyboard (Figure 36). This section provides a description of each mode.

2.8.1.1 Teach Mode

In TEACH mode, the machine is "taught" various operating parameters (motor velocities, etc.) and specific positions of mechanisms at the various stations when a particular action should take place. This is done prior to operating the machine in any of the action modes. All of the teaching is accomplished by manual entry on the machine keyboard. Various messages will appear in the display window to guide the machine operator in this mode.

2.8.1.2 Manual Mode

When manual mode is selected, (by depressing key on keyboard), the station selected (by depressing appropriate key on keyboard) can be operated independent of the remaining stations. The station selected can then be cycled by actuating the pushbuttons on the applicable control panel. A white "ON-LINE" indicator light, located on top of the control panel for station selected, will light while that station is on. The yellow CYCLE pushbutton will go out when the cycle is completed.

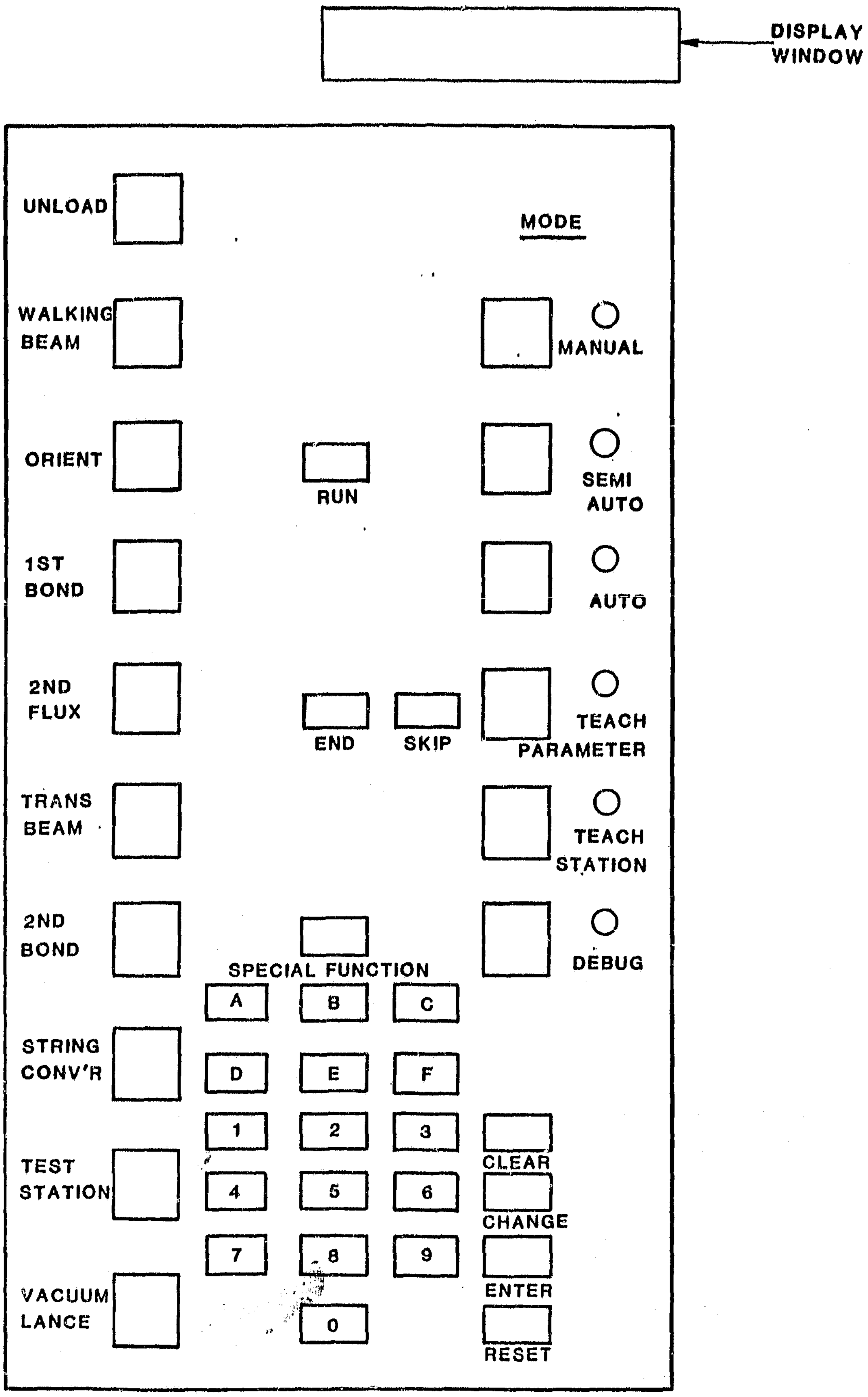


FIGURE 36 - KEYBOARD CONTROLS AND INDICATORS

Manual mode is used to verify proper operation at a specific station without having any other function take place. This allows that station to be checked out by itself before having it work in conjunction with any other function. Thus, it is a prerequisite to operate each station satisfactorily in manual mode before attempting semi-automatic or automatic modes. Changes can be made later at any given station by going back to TEACH mode, and correcting any inputs to the microprocessor control.

2.8.1.3 Semi-Automatic Mode

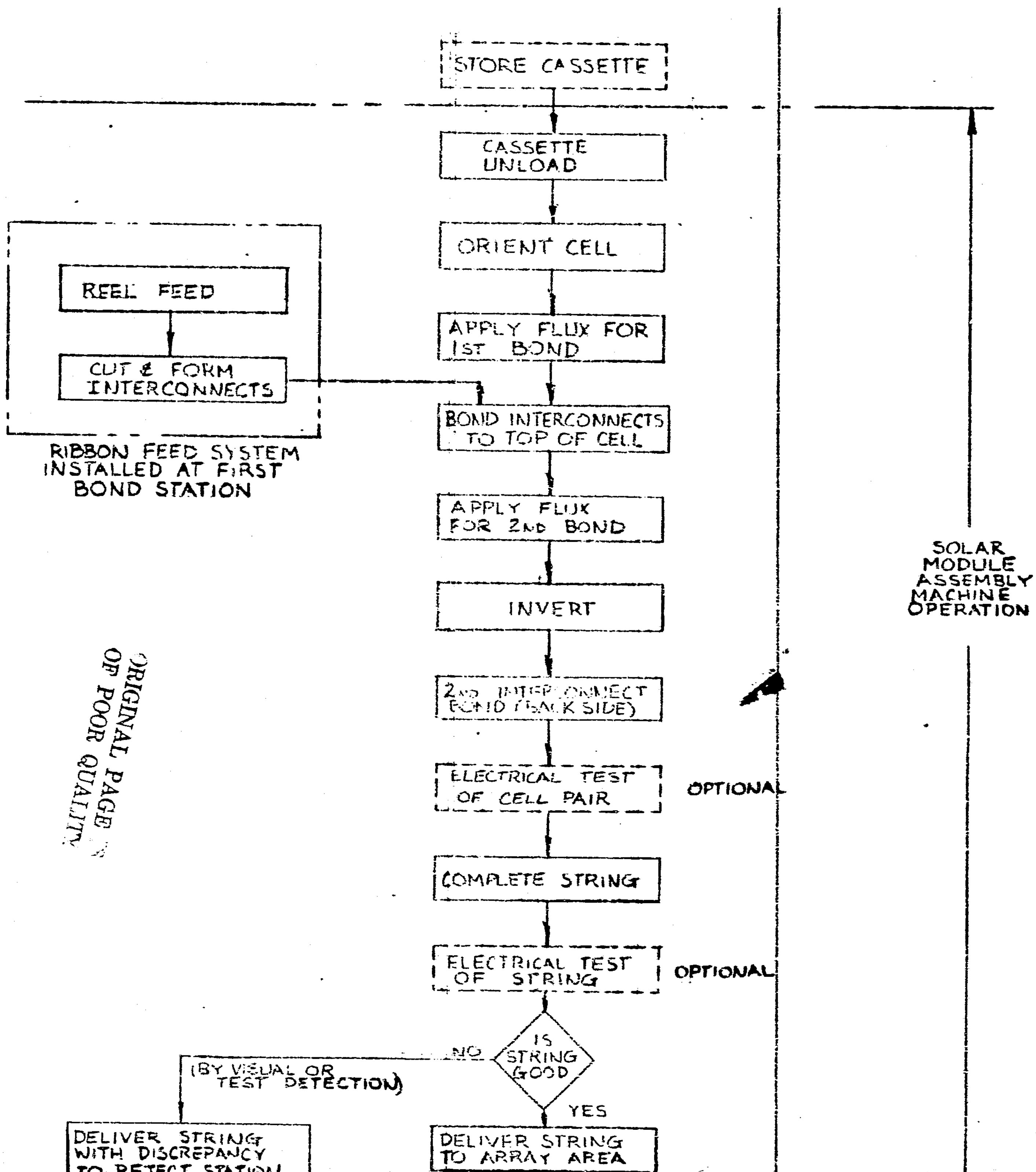
When the semi-automatic mode is selected, all of the stations of the machine will operate for one complete cycle only. The semi-automatic mode allows all the functions of the machine to be checked out with respect to the other functions simultaneously for a complete cycle before going into automatic mode for continuous operation. This mode is used during machine start-up and/or to observe machine operations at each station.

2.8.1.4 Automatic Mode

Once the machine has performed properly in the semi-automatic mode, the machine can then be operated in the automatic mode. In automatic mode, all stations of the machine will run continuously in conjunction with the microprocessor controls, interlocks, etc. from cells being unloaded from cassettes into the machine to cell strings being delivered to module array area at discharge from machine. This mode is used for demonstration, testing, and production operations.

2.8.2 SEQUENCE OF OPERATIONS

The machine operations are listed in flow diagram shown in Figure 37. The timing diagram for the operation of the machine in automatic mode is shown in Figure 38.



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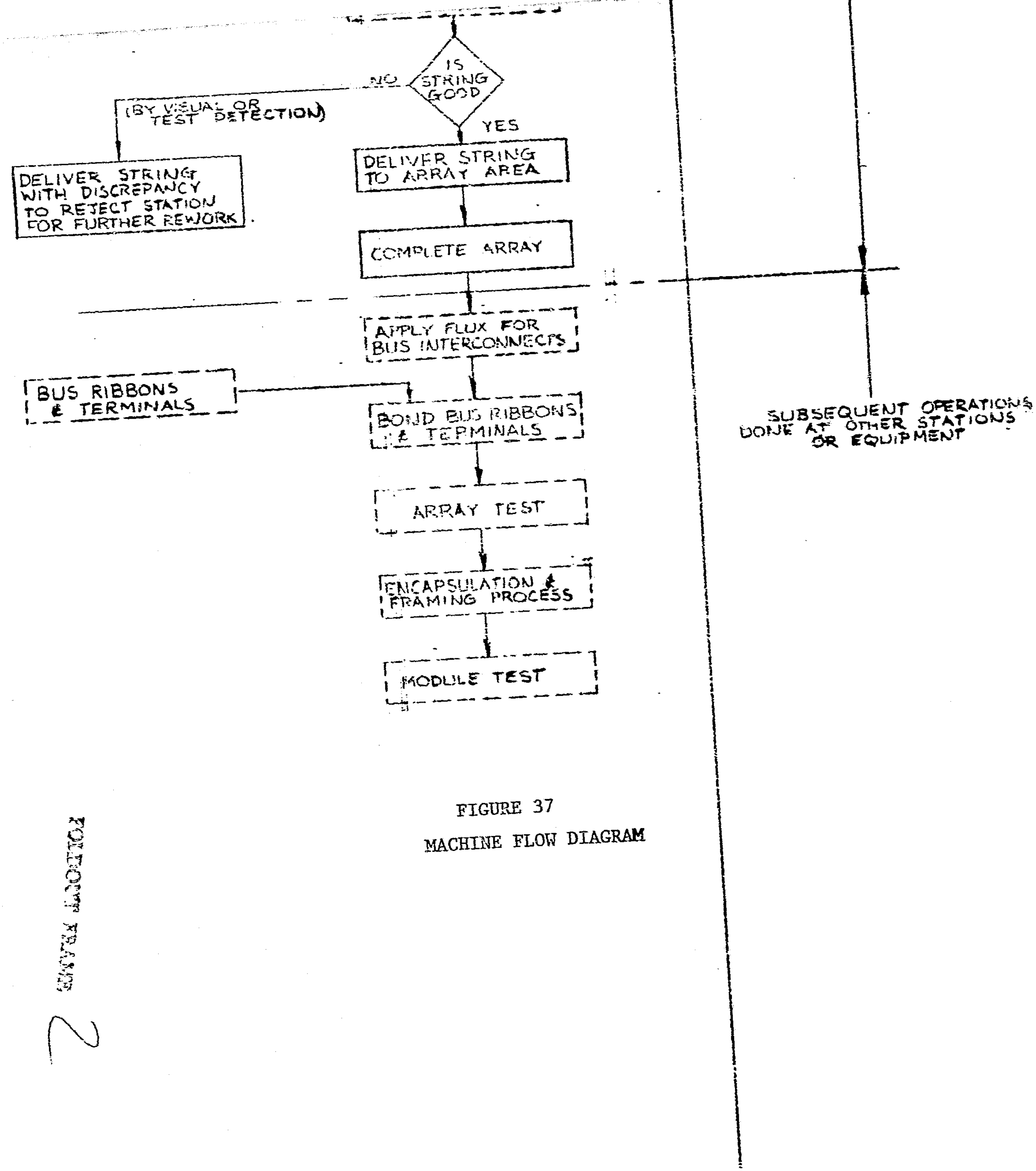

FIGURE 37

MACHINE FLOW DIAGRAM

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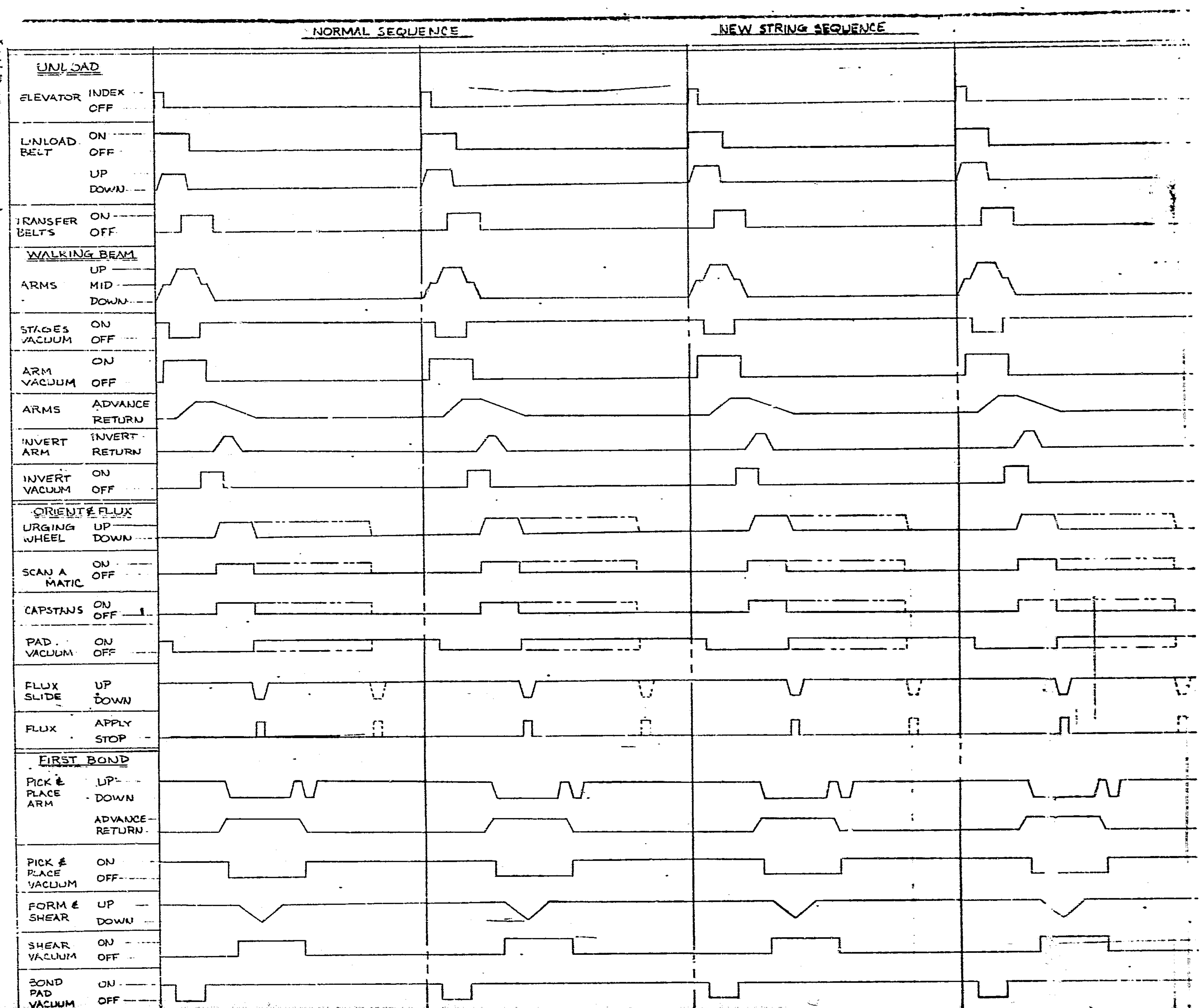

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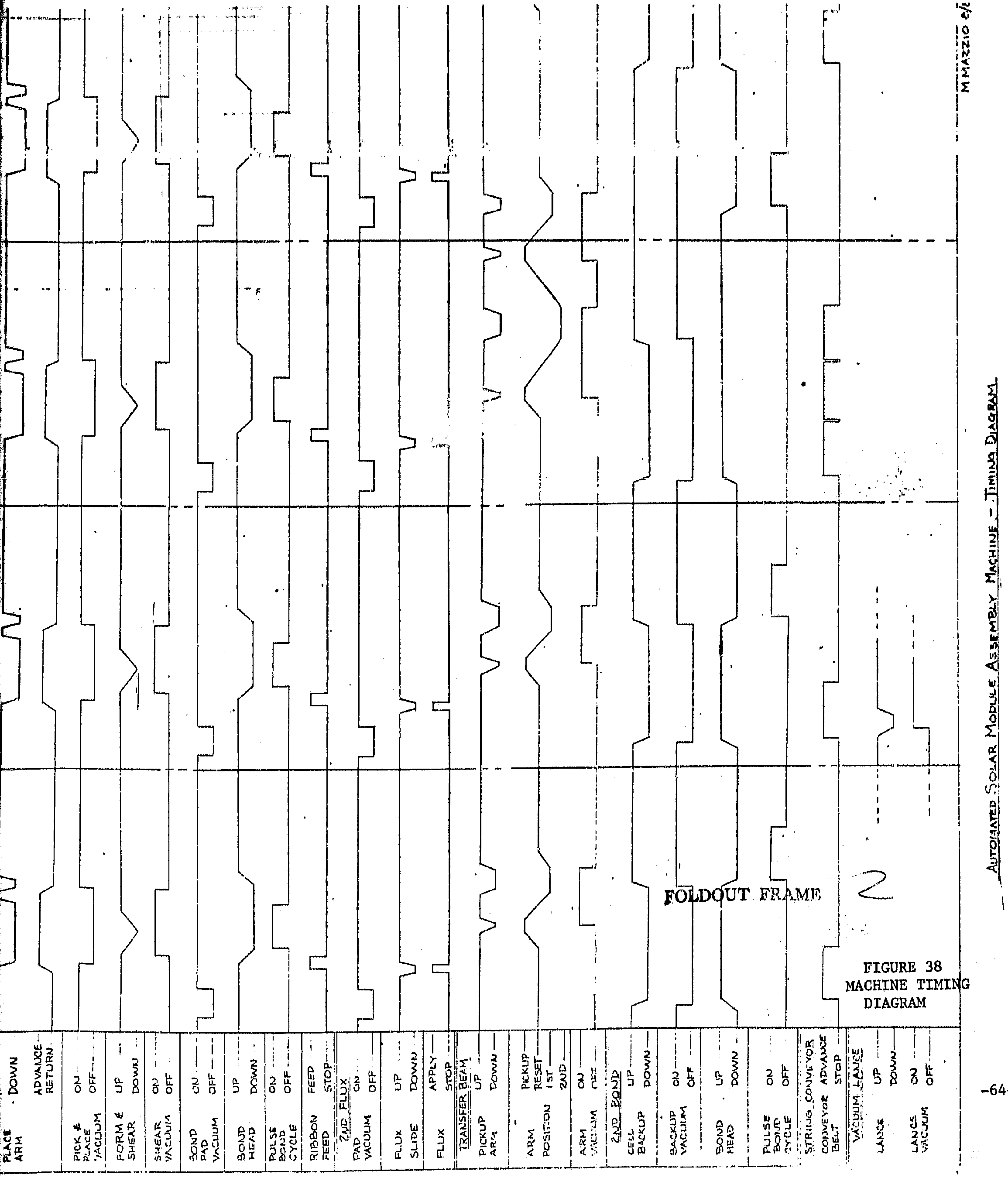


FIGURE 38
MACHINE TIMING
DIAGRAM

The basic sequence of machine operations are:

1. Dispense solar cell from cassette into machine

   a. When given a signal from an empty pad on the ready station, the cassette unloader drive belts dispense a cell out of the cassette onto the set of transverse belts that take it up to pad on the ready station.

   b. The cassette lowers until the next cell is in position to be dispensed.

   c. When empty, the cassette is raised to its unload position. The empty cassette is removed, and a full cassette is loaded on to its platform.

2. Index cell to next station (cell orient and flux application station).

   NOTE: This indexing action of the walking beam conveyor is repeated at all the stations in the first half of the machine. (See Figure 39). Interlocks prevent the action from occurring until all the functional stations have completed their cycle.

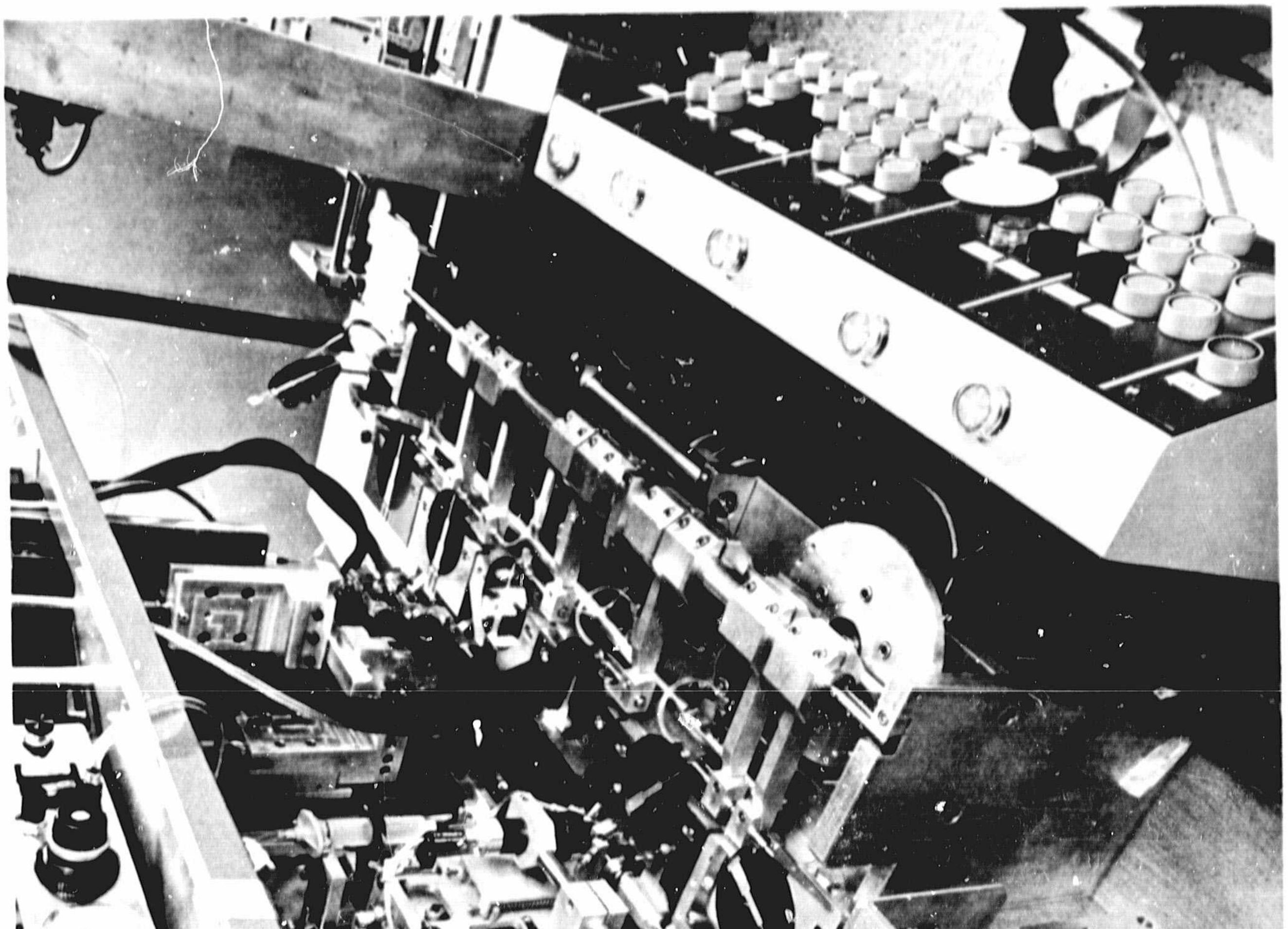


FIGURE 39 - FIRST HALF OF MACHINE - SHOWING SOLAR CELLS IN EACH STATION

a. The walking beam pick-up arm rises to the workstage level, at which it dwells while its vacuum system goes on and takes hold of the cell

b. The pick-up arm and cell rises to the top position, which is clear of any mechanism. It then advances to the next station.

c. The vacuum pick-up arm lowers the cell on to the workstage of the next station and dwells there while the workstage vacuum systems comes on to take hold of the cell, while the pick-up arm vacuum system goes off.

d. The pick-up arm then descends to its bottom position and retracts back to its start position, ready for next cycle.

3. Orient cell

a. When the sensor in the workstage of the cell orient station detects a cell, the center urging wheel rises, and urges the cell against the rotating capstan wheels. This system, rotates the cell under the optical scanning system until the cell pattern is oriented properly.

NOTE: If cell had a flat, or was square or rectangular, the straight edges would be utilized for orientation purposes, thus minimizing or eliminating the need for optical scanning system.

4. Apply flux

a. When cell is oriented properly, the flux application system is lowered, a preset amount of flux is deposited on the areas where the interconnects are to be soldered, and the flux system is raised to its reset position.

5. Index cell to first interconnect station (See Step 2)

6. Solder interconnects to cells (1st Bond)

   a. When the first interconnect workstage sensor detects a cell in position, the pick and place arm of the interconnect feed system brings a pair of interconnects forward and places them in position to be bonded.

   b. The bond head lowers until the bonding tools engage the interconnects, the pulsed heat is turned on for a predetermined amount of time which starts the soldering action. The bonding tools are thermocouple controlled to prevent them going over a preset maximum temperature and possibly damaging the cell.

   c. After the pulsed heat is turned off, the bonding tools stay in contact with the interconnects for a predetermined amount of time while the solder that has reflowed solidifies and completes the soldering action. The pick and place arm returns to pick up (by vacuum) the next pair of interconnects, which were cut to length and formed when the pick and place arm started forward in the previous cycle.

7. Index tabbed cell to 2nd flux station (See Step 2)

8. Apply flux to interconnects for 2nd (stringing) bond

   a. Same as Step 4.

9. Index tabbed and fluxed cell to buffer station (See Step 2)

   a. This station was included to provide space for anticipated mechanism in the area. Also, it is available in case another function is desired prior to cell inversion (such as another cell orient station for first or last cell in the string).

10. Index cell to cell inversion station (See Step 2)

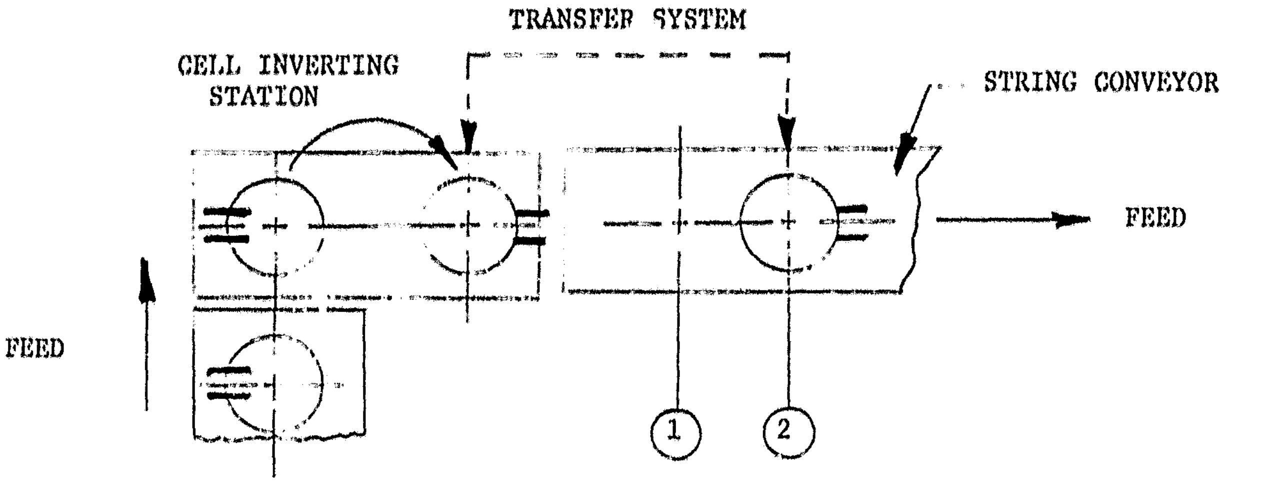
11. Invert cell and place on ready pad

   a. This action takes place as soon as the inverting arm has a cell and detects (by sensor) that the ready pad is empty in order to minimize any time delay in the second half of the machine and result in the shortest time cycle for the whole machine.

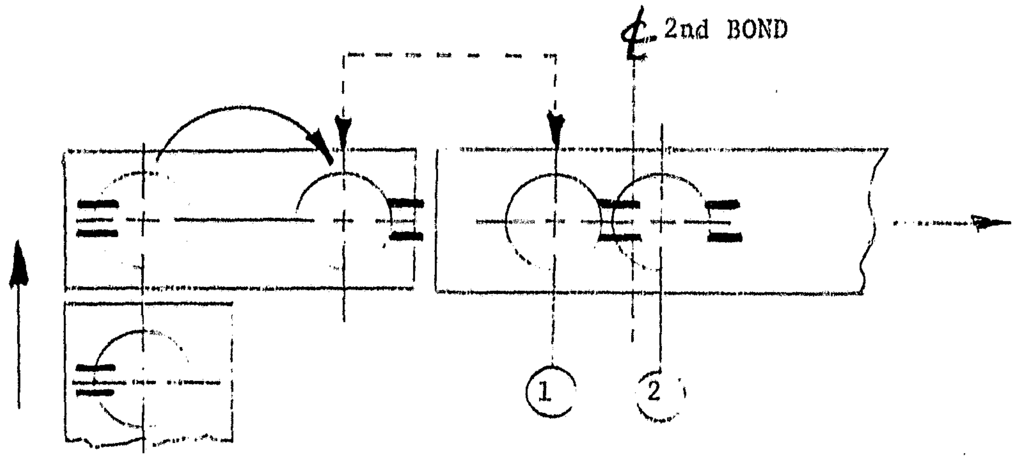
12. Transfer cell to second bond station on string conveyor

   a. The transfer pick-up arm picks up the cell from its back side from the cell inversion ready pad and delivers it to the second bond station on the string conveyor, and holds it in position, until the bonding action starts, at which time it retracts back to its ready position.

   b. As shown in Figure 40, in Step A, the first cell of any string is placed on second bond station vacuum chuck in position 2 on the string conveyor. In Step B, the next cell of the string is placed in position 1 where the tabs that project out from the cell overlie the cell in the second position on the string conveyor. Step B is repeated for the remainder for the cells in any particular string.



A. FIRST CELL OF STRING IS PLACED IN POSITION #2 ON STRING CONVEYOR



B. NEXT CELL OF STRING IS PLACED IN POSITION #1 ON STRING CONVEYOR

THIS IS REPEATED FOR REMAINDER OF CELLS FOR A PARTICULAR STRING TO ASSURE A UNIFORM POSITIONING AND SPACING OF THE CELLS IN THE STRING.

FIGURE 40 - TRANSFER TO STRING CONVEYOR

13. Index string conveyor

a. As soon as the second bond station completes its action and the bonding tools rise, the string conveyor indexes to advance the conveyor belts one intercell pitch.

b. When a cell string is completed, end of string sequence is initiated. This is a triple index of the string conveyor, in order to create a cell pitch clearance between strings. This separation between strings is necessary to permit unencumbered pick-up of each string at the vacuum discharge area.

14. Electrical test (Optional)

a. Along the string conveyor, an electrical test can be installed, if desired, to test each cell pair or the entire string. This could be a simple forward bias or continuity test. If the cells didn't pass the test, the microprocessor controls would initiate an end-of-string sequence, and start a new string. When the rejected string reached the discharge area, it would be placed in the reject station area.

15. Transfer string to module array area

a. When the sensor in the string conveyors detects a complete string arrives under the vacuum lance, the lance descends automatically to pick up the string and immediately rises to its reset position. (This allows further indexing of the string conveyor for the next string).

b. The machine operator disengages the carriage latch, and moves the carriage to the correct detent position, reengages the carriage latch, and actuates the lance cycle to deposit the string in the module array area (or reject station).

c. The machine operator then returns the lance to its pick-up position, ready for the next string.

d. If the string has to be placed in an interdigitated and reversed position in the module array area, he disengages the lance latch, rotates the lance, then moves it to proper placement in the module array area. He must rotate the lance again to return it to its original position before placing it back in its pick-up position for the next string to be picked up.

16. Unload module array area

a. When the module array format is completed, the set of strings is removed from the machine and taken to a work bench for its next operation.

2.8.3 Changeover of machine to accommodate various cells and strings

The machine, while primarily adapted to the 3 inch diameter solar cells, which were supplied for test purposes, can easily accommodate 100 mm diameter cells. In fact, much of the early development work was done on 100 mm cells.

To change the machine over from handling 3 inch diameter solar cells to 100 mm diameter cells the following steps are required:

a. Remount stop bar in ready station as cells are dispensed into machine.

b. Adjust capstan rollers to rear in cell orient station.

c. Install new ready pad at cell inversion station

d. Install new set of string conveyors with positioning fixtures located to dimensions required by 100 mm cell and string intercell pitch

e. Adjust vacuum pick-up cups on vacuum lance to cell spacing

In addition, there may have to be adjustments made to the positions of flux dispensing tubes, and the bonding tool electrodes, if the interconnect bond locations are different. However, these adjustments may have to be made any time a different solar cell is to be processed, even one with the same size dimensions. The string conveyor can accommodate a particular cell size with fairly wide tolerances, but gives only one intercell pitch for the cell string. If a new string has to have a different pitch, the string conveyor belts will have to be replaced. The die set in the first bond station has to be replaced in the case of a different size interconnect or a change in its spacing.

For the machine to accommodate other shaped cells, such as square, rectangular, half round or quarter round, assuming they are brought to the machine in similar commercially available cassettes, the same general steps must be followed, which are:

1. Proper positioning in first ready station, in position to be picked up by walking beam conveyor through first half of machine.

2. Proper orientation and positioning in cell orient station, using flat edges where available.

3. Adjustment of flux dispensing tubes and bonding tool electrodes to bond site locations.

4. Cell inversion ready pad installed for the particular cell size and shape.

5. String conveyor belts with positioning fixtures for given inter-cell pitch.

6. Adjust vacuum pick-up assemblies on vacuum lance to proper spacing for given cell and string.

2.8.4 Machine Performance Tests and Characteristics

After teaching the machine its operating parameters and critical positions at each functional station, it was preliminarily tested in manual, semi-automatic and automic modes. An acceptance test of one hours run in automatic mode was performed for JPL personnel.

Some of the performance characteristics that the machine experienced in these tests are covered in the following sections.

2.8.4.1 Machine Cycle Time

Tests in the automatic mode confirmed that the 5 second per cycle goal was realized. These tests were made by running complete cassettes of 25 cells through the machine.

2.8.4.2 Cell Handling and Breakage

There was no evidence of any cell damage due to the handling of the cells through the machine. However, a few cell cracks did appear, although rarely, after the second bond station. For example, during the performance tests 2 cracked cells occurred in a trial run of approximately 800 cells. Due to the infrequency of their occurrence, it is not known whether the cracks were caused by the bonding action, were the result of some flaws in the cells that showed up after being heated up several times, or were due to some other reason.

2.8.4.3 Cell Orientation

The optical recognition system in the cell orient station is based on the differential contrast between the metallized surface where the interconnects are bonded and the collector surface with its anti-reflective (AR) finish. When the AR coating is not lined up properly with the metallized

surface area, which was experienced on several cells, it causes a difference in the surface finish on the metallized surface. This deviation has the appearance of a matte finish as compared to the brighter, more reflective surface of the metallized portions of the cell. This, in turn, tends to confuse the optical scanning system and results in a slight misalignment of the cell. This misalignment causes the interconnect ribbons to be bonded slightly askew from their normal position. So far the amount of the misalignment has not resulted in the interconnects not being properly bonded.

This situation can be avoided, and the problem eliminated, by careful attention to the application of the AR coating in relation to the metallized surface by the cell manufacturer.

2.8.4.4 Flux Application

The flux used in the machine is Superior Water Soluble Flux #77. In normal operation, no problem was experienced with the application of the flux onto the solar cell or ribbon interconnect. However, when the machine sits idle for a period of time, the flux application needles tend to drip. If left idle for extended periods of time, the flux tends to congeal at the exit tip of the needles. These problems were minimized through refinement in the settings of the flux application system and modifying the flux to get a higher viscosity.

2.8.4.5 First Interconnect (Bond) Station

The interconnects were bonded using pulsed heat technology. The settings on the machine for bonding the sample cell were as follows:

Bond Time	-	0.8 sec.
Dwell Time	-	1.0 sec.
Temperature Setting	-	650° C

The sample cell has metallization of Ti-Pd-Ag on both sides. This metallization on the sample cell makes for short bond time cycles with uniform results of high bond pull forces. Earlier in the project, other solar cells, such as solder dipped cells, were bonded which required longer bond time settings (1.5 seconds), and longer dwell time (1.5 seconds). The short duration of the bond pulse results in the cell reaching a temperature slightly above the solder melt temperature (188° C). When the time setting was less than 0.8 seconds, the solder did not reflow, signifying that it did not reach the melt temperature at the bond interface.

2.8.4.6 Bond Pull Tests

First and second bonds were pull tested for strength data with a Scherr-Tumico force gauge (0 - 1000 gms.). Bonds consistently held up to the maximum gauge reading of 1000 grams. Further force was applied until failure mode occurred, which was the cell cracking - interconnection/cell bond remained intact.

2.8.4.7 Electrical Tests

It became apparent that it would be desirable to have a separate means to test the I-V characteristics of the solar cells before and after bonding to see if the bonding operation has deteriorated cell performance. RCA Laboratories, Princeton, New Jersey, had developed a lamp simulator and electrical test system to obtain accurate and reproducible values of these characteristics on a different contract in the LSA program.

Arrangements were made with Robert D'Aiello of RCA Laboratories to visit the Kulicke and Soffa plant and bring the electrical test system with him for K&S to use on our project. The use of this system was a great help to us in our testing program, and we are grateful to RCA for making it available to us. (See Figure 41).

The lamp simulator was used to test bonded solar cells to determine if the bonding operation had any degrading effect on the cell. I-V profile

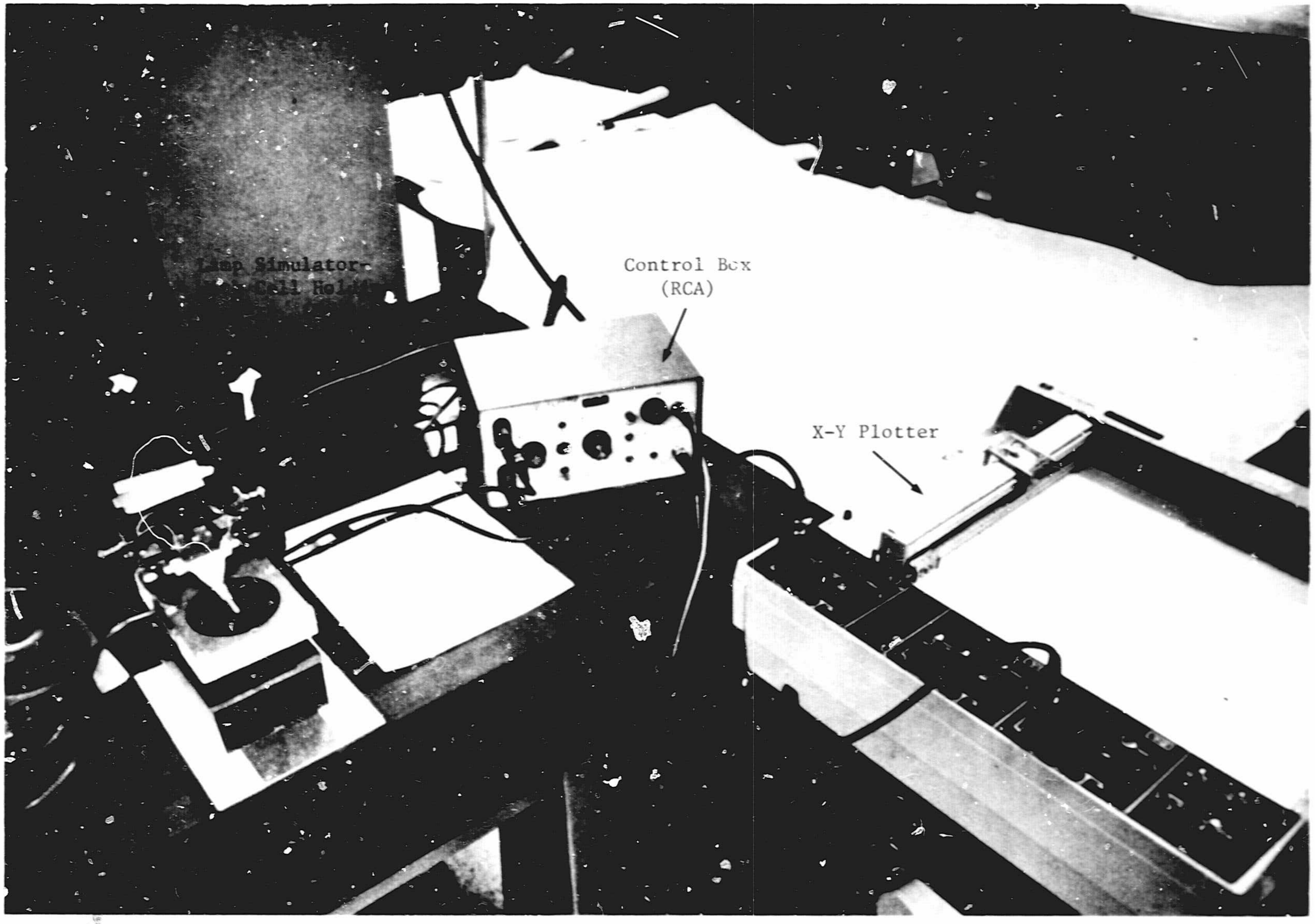


FIGURE 41 - SOLAR CELL ELECTRICAL TEST SYSTEM

curves taken of these sample cells, before and after the bonding operation indicate no apparent effect on the electrical characteristics of the solar cell by the bonding operation. (See Figure 42).

2.8.4.8 Bonding Tools

During the test runs in automatic mode, it became apparent that the bonding tool electrodes should be cleaned periodically to achieve continuous uniform bonding results. They were cleaned during these tests approximately every 200 cells. This was accomplished by inserting a piece of emory paper on the bonding station workstage and depressing the bond head assembly until the bond tool electrodes engage the emory paper. One pass of the emory paper, (pulling it out from under the bonding tools) was sufficient to accomplish the cleaning operation.

When further examination of some apparently good second (stringing) bonds were found to be either just lightly bonded or not bonded at all, (this occurred occasionally on one interconnect of the pair) further investigation turned up possible causes for this. One tool was an older style (heavier) design, which caused it to heat up more slowly. This gives different heat curves for this tool. In addition, the tool was overhanging the ribbons by approximately .010 to .015 inches, which aggravated the heat transfer to the bond interface by this tool. When the bonding tool was machined to the latest configuration and conformed to the other tool, positioned more accurately to eliminate the overhang, and the tool cleaning routine followed, the problem of occasional bad second bonds did not occur in additional test runs.

2.8.4.9 Cell String Placement

An important point for verification was the accuracy of placement of the cell strings in the module array area. This was checked out and illustrated by placing additional layers of cell strings on the original layer deposited on the platen in this area. It was difficult to discern, even with 2 or 3 layers of cell strings, that there was more than one layer deposited on the platen.

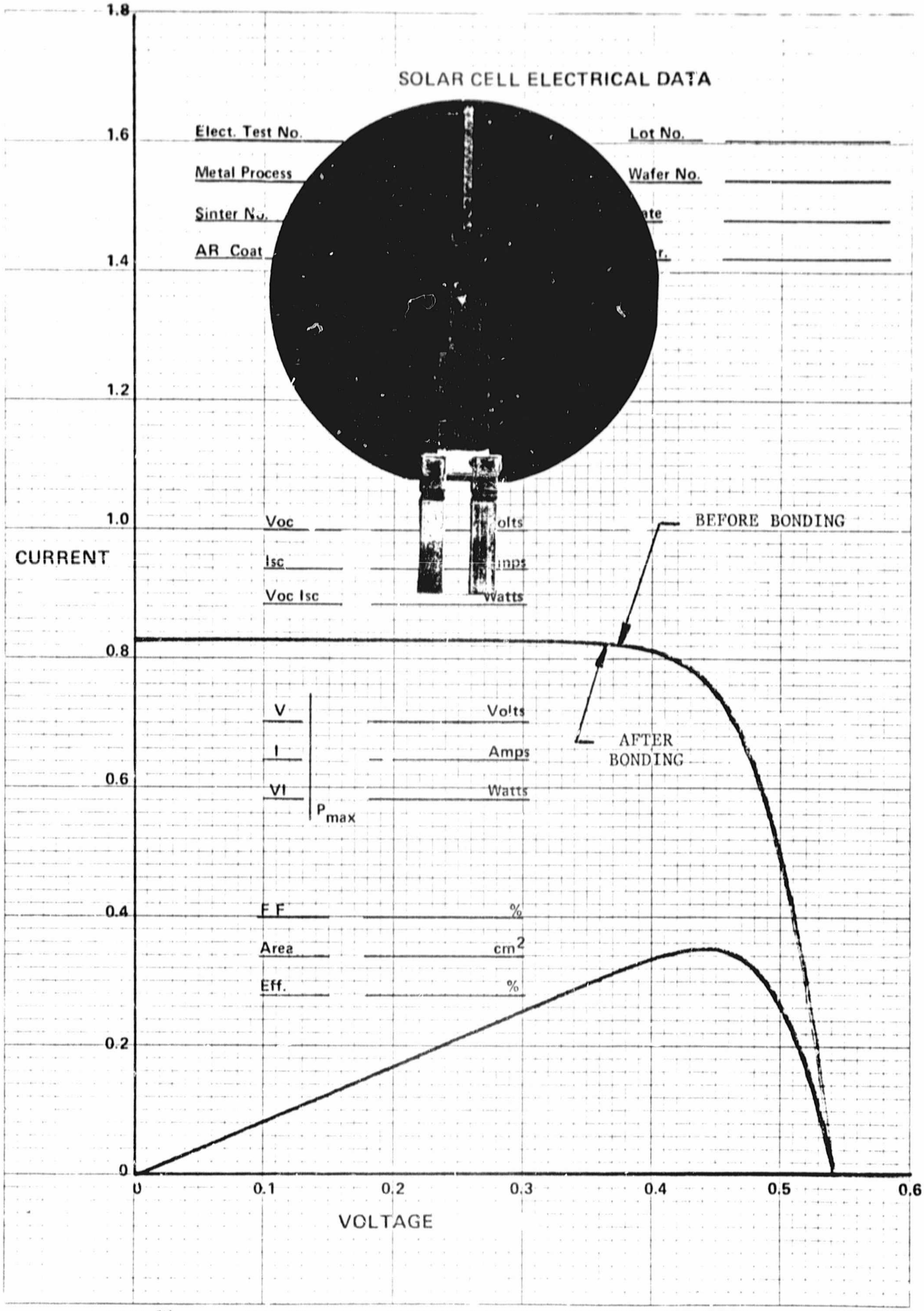


FIGURE 42 -- I-V PROFILE CURVES - RELATIVE READINGS

This verified two performance characteristics of the machine:

1. The strings were being formed with a high degree of uniformity in spacing between cells on a continuous basis - from batch to batch.

2. The pick-up and deposition of the cell string by the vacuum lance was consistently accurate, and did not result in any shifting of cells in either action.

This characteristic is important if the vacuum discharge system would have to place the cell strings in a fixture in the module array area, as would be envisioned in a user application situation.

2.9 Conclusions

a. The machine verified that the assembly of solar cells can be automated, and can be accomplished on a continuous basis at high production rates without damage or deterioration to the cells, either by the handling or bond techniques.

b. Automation techniques can accommodate normal manufacturing cell tolerances, interconnect configurations, feed and placement requirements and still result in a high degree of uniformity and accuracy of the formation and placement of cell strings.

c. It is fairly easy to change over the machine to accommodate cells of various sizes of the same shape. There could be some design modifications required to handle cells of different shapes, although they are considered at present to be minor to go from a round cell to a square cell or vice versa. With completed designs, the changeovers described could take place in approximately a half day.

d. Since the design logic of the machine is fairly straightforward, and universal in logic and application, it is conceivable that potential users, who do not have production requirements that would require a dedicated automated line at present, could be interested in and utilize various stations or sections of the machine rather than the whole machine. In particular, this could be true for the bonding or tabbing operation of the interconnects, both on individual cells and the stringing of a series of cells together.

e. Although induction heating was not used as the bond technique, it did have some beneficial aspects, and could be considered as a candidate bond technique, with further development needed.

f. In a production machine in which the bonding tool engages the work to accomplish a solder bond, a tool cleaning mechanism should be incorporated to clean off the face of the tool on a periodic basis.

g. Bond monitoring feedback circuitry would be desirable in a production machine.

SECTION 3

3. ECONOMIC ANALYSIS (SAMICS STUDY)

Economic analysis of the machine built under this contract was accomplished using the Solar Array Manufacturing Industry Costing Standard (SAMICS). The detailed information (Format A and Supporting data) are included in Appendix C. The cost data was based on 1979 dollars.

SECTION 4

4. NEW TECHNOLOGY

The following new technology items were uncovered during this program and New Technology reports filed:

a. Modification of K&S computer for application to microprocessor control of solar cell array assembly
b. String conveyor modifications to eliminate problem of tooth and belt sprocket hole pitch
c. Vacuum pick-up assembly
d. Overall solar cell array assembly machine design
e. Vacuum lance
f. Walking beam conveyor
g. Automatic orientation and flux application of solar cells
h. Automatic cell interconnection
i. Inverting of solar cells
j. Solar cell string conveyor
k. Automatic string interconnection of solar cells
l. Vacuum transfer to module array format

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

APPENDIX A

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] INTCONSTR

A2 [Descriptive Name] Automated cell interconnect, stringing and string applique machine

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] CELL STRG

A4 Descriptive Name [Product Name] Interconnected cells in strings which are applied to module array configuration.
Assume: (15) 3 inch diameter cell/string - 4 strings/module

A5 Unit Of Measure [Product Units] Strings

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) .8 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 6.833* Calendar Minutes (Used only to compute in-process inventory) (82 cells-avg mach load / 12 cells/min

A8 Machine "Up" Time Fraction [Usage Fraction] .95 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	INTERCON	STRING	COMPUTER
A9a	Component [Descriptive Name] (Optional)	Cell Feed & Interconnect System	Serial Stringing & Delivery System	Microprocessor Controls
A10	Base Year For Equipment Prices [Price Year]	1979	1979	1979
A11	Purchase Price ($ Per Component) [Purchase Cost]	92,500	69,500	20,000
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	7
A13	[Salvage Value] ($ Per Component)	5,000	2,000	1,000
A14	[Removal and Installation Cost] ($/Component)	500	500	0

* In-Process inventory based on input of 25 cell cassette and output of module's worth of strings. (See attached Explanation).

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

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Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) INTCONSTR

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	140	Sq ft	Mfg. Floor Space - Type A
B3064D	1	Person/Shift	General Assembly
B3736D	.05	Person/Shift	Maint. Mechanic

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	.02166	KWH/min	Electricity
C2032B	5.24	Ft^3/min	Compressed Air
	.054	gm/min	Solder Flux
	24	units/min	Interconnects @ $.01/interconnect

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
Cells	.999	1/15 = .0667	Strings/Cell	Solar Cells

Prepared by *Max Bycer* Date *8/19/80*

* 100% minus percentage of required product lost.
** Assume 100% yield here.
*** Examples: Modules/Cell or Cells/Wafer.

REVERSE SIDE JPL 3037–S R 10/78

EXPLANATION OF FORMAT A INPUTS

INTRODUCTION

The machine to be delivered under this contract is a cell stringing and string applique machine capable of handling a variety of cells (3 inch diameter used in examples) and assembling strings of cells which can then be placed in a matrix up to 4' X 2' in series or parallel arrangement. The target machine cycle is to be 5 seconds per cell. (See Figure 1).

Since this equipment is of a continuous process nature, with no reserve or build up of inventory except at the input and discharge, a single Format A was filled out. Supporting data for each station, as required, is attached.

The data supplied is based on 3 inch diameter solar cells loaded into the machine in a standard 25 level cassette. These cells are entered into the machine after which certain operations are performed on them at various stations continuously on a 5 second cycle. They are then assembled into strings and transferred to a discharge area. Since the machine has been designed to handle strings up to 4 foot long, calculations were based on a string of fifteen (15) 3 inch diameter cells as the output from the machine as deposited in a module array of four (4) 15 cell strings.

PART 2 - PROCESS CHARACTERISTICS

A-6 Output Rate = .8 minute

Based on 12 solar cells processed per minute and an output of a 15 cell string. $\left(\frac{12 \text{ cells/min}}{15 \text{ cells/string}} = .8 \frac{\text{string}}{\text{minute}}\right)$

A-7 Average Time at Station = 6.833 minutes

Since this entry is used to calculate in-process inventory, it was felt that the proper unit of inventory is the solar cell. The calculation was based on each station of the machine filled with a solar cell, with the cell in the first station just being issued from the entry cassette. The entry cassette then goes from full to empty, with average condition being half full. (12 cells). The same applies to the module array, where the in-process inventory goes from 0 to 4 strings of 15 cells each, the average condition being 2 strings of 15 cells.

Therefore, the in-process inventory of solar cells are:

Cassette		Tabbing Area		Second Interconnect and Test		String Conveyor		Vacuum Transfer Area		Module Array Area		
12	+	7	+	3	+	15	+	15	+	30	=	82 cells

$$\frac{82 \text{ cells}}{12 \text{ cells/minute}} = 6.833 \text{ minutes}$$

A-8 Machine "Up-Time" Fraction = .95

This is an arbitrary determination based on the assumption that the machine has a targeted yield of 95%, and to achieve this the machine will have a "down time" of 5%.

PART 3 - EQUIPMENT COST FACTORS

A-9 Component Referent

1. INTERCON - This is the area of the machine where the cell is fed into the machine, oriented, flux applied, interconnects ribbons applied to the cell, and flux applied to the ribbons in readiness to be joined together into strings.

Equipment Cost (A-11)

Cassette Unloader (4)	$ 15,000
Input Feed System	2,000
Walking Beam Conveyor	5,000
Cell Orient Station	10,000
Flux Applicator System	4,000
1st Interconnect System (including ribbon feed system)	50,000
2nd Flux Application System	4,000
Cell Inverting Station	2,500
	$ 92,500

2. STRINGCON - This is the area of the machine where the individual cells, with interconnect ribbons attached, are joined into strings, each pair of cells tested electrically to verify that a good bond was made, and conveyed into a vacuum transfer area, where they are transferred onto a platform in a module array configuration.

Equipment Cost (A-11)

Transfer to String Conveyor	$ 5,000
String Conveyor	12,000
2nd Interconnect	25,000
String Test System (Optional)	2,500
Vacuum Transfer System	25,000
	$ 69,500

3. COMPUTER - These are the computers that will be used for microprocessor control of the machine.

Equipment Cost (A-11)

(2) K&S Computers @ $10,000	$ 20,000
Grand Total	$ 182,000

PART 3 - EQUIPMENT COST FACTORS

A-10	Base Year for Equipment Prices	=	1979
A-11	Purchase Price (see detailed list above) Based on items already purchased and estimates on the remaining items.	=	$182,000
A-12	Anticipated Useful Life From 5101-33 Interim Price Estimation Guidelines, Page 2-1	=	7 years
A-13	Salvage Value - $ per Component		
	A. INTERCON	=	$5,000
	B. STRINGCON	=	$2,000
	C. COMPUTER	=	$1,000
	Arbitrary assumption		
A-14	Removal and Installation Costs		
	A. INTERCON	=	$500
	B. STRINGCON	=	$500
	C. COMPUTER	=	$ 0
	Arbitrary assumption		

PART 4 - DIRECT REQUIREMENTS

A. Floor Space - Type A = 140 sq. ft.

The floor space estimation of 140 square feet was obtained from the drawing of the machine system (Figure 1) and allows for space around the machine for operation and servicing where indicated.

B. Labor

It is assumed that one person is needed to operate the machine under normal conditions. He would spend approximately 2/3rds of this time at the discharge end of the machine (vacuum transfer area) moving completed strings to their designated location. The other third of his time would be to load and unload the cassettes at the input of the machine. The operator would also clear many of the machine jams that might occur during operation. Thus, the need for a maintenance mechanic has been arbitrarily set for 5% of the time (or .05 person/shift).

It should be noted that, since the machine delivers a module array of strings at a time, this should lessen the labor requirements for module assembly.

PART 5 - DIRECT REQUIREMENTS PER MACHINE PER MINUTE

The utilities and commodities requirements are found on the attached schedules for electricity, compressed air, solder paste, and ribbon interconnect. These calculations were based on the requirements per cycle (5 seconds) at the various stations, which were then averaged out over the entire cycle, and divided to get the requirements per minute.

PART 5 - DIRECT REQUIREMENTS PER MACHINE PER MINUTE

A. ELECTRICITY - CATALOG NUMBER - C1032B

STATION	USAGE	TOTAL KWH/min
1. Cassette Unload	4 stations - only one station operates at a time 2 motors @ 15 watts each @ 1 sec/cycle $2 \times 15 = 30 \times \frac{1}{5} =$ avg usage $= \frac{.006\ \text{KW}}{60} =$	.0001
2. Input Feed into machine (from cassette)	Belt motor - 15 watts for 1 sec/cycle $15 \times \frac{1}{5} = 3$ watts avg usage $= \frac{.003\ \text{KW}}{60} =$	.00005
3. Walking Beam Conveyor	Z motor - 20 watts @ 5 sec/cycle = 10 watts/cycle Hor. motor - 30 watts @ 1.5 sec/cycle = 45 watts/cycle 4 Solenoids - 10 watts each = 40 watts 40 watts @ 2½ sec/cycle - 100 watts/cycle $\frac{10 + 45 + 100}{5} = 31$ watts avg usage $= \frac{.031\ \text{KW}}{60} =$	.0005
4. Cell Orient & Flux Application	Urge motor - 10 watts @ 5 sec/cycle = 50 watts/cycle Rotary motor - 20 watts @ 1 sec/cycle = 20 watts/cycle Flux Dispenser Drive - 15 watts @ 1 sec/cycle = 5 watts/cycle Z Solenoid - 20 watts @ 1 sec/cycle = 20 watts/cycle Flux Solenoid - 7 watts @ 3 sec/cycle = 21 watts/cycle Light - 10 watts @ 5 sec/cycle = 50 watts cycle $\frac{50 + 20 + 5 + 20 + 21 + 50}{5} = 35.2$ watts avg usage $= \frac{.0352\ \text{KW}}{60} =$	.0006
5. 1st Interconnect	Z motor - 30 watts @ 1 sec/cycle = 30 watts/cycle Strip Fad motor - 15 watts @ 5 sec/cycle = 7.5 watts/cycle Cut-off & Shear motor - 40 watts @ 1 sec/cycle = 40 watts/cycle Pick & Place Hor. motor - 30 watts @ 8 sec/cycle = 24 watts/cycle Pick & Place Vert. motor - 15 watts @ 8 sec/cycle = 12 watts/cycle $\frac{30 + 7.5 + 40 + 24 + 12}{5} = 22.7$ watts avg usage for motors Pulsed heat for Bond - 300A X 2.8V for .6 sec + 150A 2.8V for 4 sec $\frac{672 \text{ watts sec/tool}}{5} = 134$ watts avg usage/tool Total - 22.7 + 134 + 134 = 290.7 total watts avg usage = $\frac{.2907\ \text{KW}}{60} =$	.0048

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A. ELECTRICITY - CATALOG NUMBER - C1032B

STATION	USAGE	TOTAL KWH/min
6. 2nd Flux Application	Flux Dispenser - 15 watts @ 1 sec/cycle Solenoid - 10 watts @ 1 sec/cycle $\frac{25}{5}$ watts = 5 watts avg usage = $\frac{.005 \text{ KW}}{60}$ =	.0001
7. Transfer to String Conveyor	Z motor - 15 watts @ 2 sec/cycle Hor. motor - 30 watts @ 2 sec/cycle Solenoid - 7 watts @ 2 sec/cycle 52 watts @ 2 sec/cycle = $52 \times \frac{2}{5}$ = 21 watts avg usage = $\frac{.021 \text{ KW}}{60}$ =	.0004
8. String Conveyor	DC motor - approx. 75 watts @ 1 sec/cycle $75 \times \frac{1}{5}$ = 15 watts avg usage = $\frac{.015 \text{ KW}}{60}$ =	.0003
9. 2nd Interconnect	Z motor - 30 watts @ 1 sec/cycle $30 \times \frac{1}{5}$ = 6 watts avg usage 2 Solenoids - @10 watts each = 20 watts @ 2 sec/cycle $20 \times \frac{2}{5}$ = 8 watts avg usage Pulsed Heat - 300 AMP = 300 AMP X 2.8V X .6 sec/cycle + 150 X 2.8 X .4 = 672 watt sec/tool $\frac{672}{5}$ = 134 watt avg/tool Total = 6 + 8 + 134 + 134 = 282 watt avg usage = $\frac{.282}{60}$ =	.0047

A. ELECTRICITY - CATALOG NUMBER - C1032B

STATION		USAGE	TOTAL KWH/min
10.	String Test (Optional)	Test Rig Actuation motor - 20 watts @ 1 sec/cycle $20 \times \frac{1}{5} = 4$ watts avg usage $= \frac{.004}{60} = .000067$	.00007
11.	Vacuum Transfer	Z motor - 40 watts @ $\frac{2}{15}$ sec/cycle = 5.3 watts/cycle θ Latch Solenoid - 10 watts @ $\frac{3}{15}$ sec/cycle = 2 watts/cycle Trigger Solenoid - 10 watts @ $\frac{5}{15}$ sec/cycle = 3.3 watts/cycle Vacuum Solenoid - 10 watts @ $\frac{2}{15}$ sec/cycle = 1.3 watts/cycle $5.3 + 2 + 3.3 + 1.3 = \frac{11.9}{5} = 2.4$ watts avg usage = $\frac{.0024 \text{ KW}}{60}$	.00004
12.	Overall Integration Control Systems	2 computers @ .2 KW each 1 water pump @ .2 KW Total $\frac{.6 \text{ KW}}{60}$ =	.01
		Total Electrical Requirements	.02166

PART 5 - DIRECT REQUIREMENTS PER MACHINE PER MINUTE

B. COMPRESSED AIR - CATALOG NUMBER - C2032B

STATION	USAGE	TOTAL Ft^3/min
3. Walking Beam Conveyor	20 psi (30 CFH) @ 2 sec/cycle - 6 valves - $\frac{\text{3 valves on}}{\text{3 valves off}}$ $3 \times 30 \text{ CFH} \times \frac{2}{5} = \frac{36}{60}$ CFH avg usage =	.6
4. Cell Orient & Flux Application	60 psi (60 CFH) @ 1/10 sec/cycle $60 \text{ CFH} \times \frac{1}{50} = \frac{1.2}{60}$ CFH avg usage =	.02
6. 2nd Flux Application	60 psi (60 CFH) @ 1/10 sec/cycle $60 \text{ CFH} \times \frac{1}{50} = \frac{1.2}{60}$ CFH avg usage =	.02
7. Transfer to String Conveyor	20 psi (30 CFH) @ 2 sec/cycle = $30 \times \frac{2}{5}$ = 12 CFH avg usage $\frac{12}{60}$ CFH =	.2
8. String Conveyor	20 psi (30 CFH) @ 4 sec/cycle = $30 \times \frac{4}{5}$ = 24 CFH avg usage $\frac{24}{60}$ CFH =	.4
11. Vacuum Transfer	30 vac. valves on 20 sec/string cycle @ 30 CFH $30 \times 30 = 900 \text{ CFH} \times \frac{20}{75} = 240$ CFH avg usage $\frac{240}{60}$ CFH =	4
	Total Compressed Air Requirements	5.24

PART 5 - DIRECT REQUIREMENTS PER MACHINE PER MINUTE

TOTAL

C. SOLDER FLUX - Source: Superior Flux & Mfg. Co
Cleveland, Ohio

COST DATA

1 lb. @ \$2.65 = \$5.84 kg = \$.00584 gm

VOL: 1 in^3 = .1 lb. = 45.4 gm

Dispensing rate: .040 dia. X .02 thick = 2.51×10^{-5} in^3/drop

= 2.51 X 4 drops/cell = 1.014×10^{-4} in^3/cycle

= $\frac{1.004}{5} \times 10^{-4}$ = .00002 in^3/sec

= .00002 X 60 = .0012 in^3/min

= .0012 X 45.4 = .054 gm/min

D. INTERCONNECTS

COST DATA

Reel of copper ribbon, tinned, and cut and formed = \$10.00/1000
= \$.01/unit

2 interconnect ribbons/cell =

2 X 12 cells/min = 24 interconnects/min = 24 units/min